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DEVELOPMENT OF A 1000-WATT MULTI-OUTPUT POWER CONDITIONER FOR CONTROL OF MERCURY-ION ELECTRIC THRUSTOR ENGINES

by

Paul Knauer

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-7938

Westinghouse Electric Corporation
Aerospace Electrical Division
Lima, Ohio

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SUMMARY REPORT

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LIMA, OHIO 45801

DEVELOPMENT OF A 1000-WATT MULTI-OUTPUT POWER CONDITIONER FOR CONTROL OF MERCURY-ION ELECTRIC THRUSTOR ENGINES

By Paul Knauer
Westinghouse Electric Corporation

ABSTRACT

The power conditioner is designed to operate from a solar-cell array, and provides eight isolated outputs ranging from 4 volts at 50 amperes ac to 3000 volts at 0.25 amperes dc. All outputs are self-protecting against overloads and short circuits, and are designed to withstand repetitive arcing to any terminal, a basic characteristic associated with electric engine operation. The power conditioner utilizes a magnetic oscillator to change the dc input to an ac voltage capable of being transformed to the desired level. Magnetic amplifiers provide pulse-width-modulated control of all regulated outputs.

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DEVELOPMENT OF A 1000-WATT MULTI-OUTPUT POWER CONDITIONER FOR CONTROL OF MERCURY-ION ELECTRIC THRUSTOR ENGINES

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SUMMARY

The purpose of this contract was to develop a multi-output power conditioner capable of changing the output of a solar-cell array to usable, controlled power necessary for the operation of an electric thrustor engine. One breadboard model of the power conditioner was built, tested, delivered to NASA and operated successfully with a mercury-ion engine.

INTRODUCTION

The power conditioner described herein is designed to provide eight controlled outputs, required for proper operation of a mercury-ion thrustor engine. It operates from a solar-cell array capable of providing 40 to 60 volts ac at a nominal current of 33 amperes.

The power conditioner utilizes a magnetic oscillator to provide alternating voltages capable of being transformed to any voltage level. These transformers provide the required isolation between the eight output stages and the power conditioner control circuits.

The nominal outputs provided by the power conditioner with a 45 volt input are as follows:

Supply	Voltage	Current	Watts
Feed	6 volts AC or 3 volts AC	3 amps AC 6 amps AC	18
Cathode	4 volts AC	50 amps AC	200
Anode	36 volts DC	7 amps DC	252

Supply	Voltage	Current	Watts
Screen	3000 volts DC	0.25 amps DC	750
Accelerator	2000 volts DC	0.05 amps DC	100
Neutralizer Cathode	6 volts AC	7 amps AC	42
Neutralizer Vaporizer	3.2 volts AC	3.2 amps AC	10
Neutralizer Bias	55 volts DC	0.055 amps DC	--
		Total	1372

The detailed volt-ampere characteristics of each of these supplies is presented in the Appendix.

POWER CONDITIONER OPERATION

Layout

Figures 1 through 5 show various views of the power conditioner. Each circuit board as well as individual chassis-mounted components are labelled for purposes of identification. Care must be exercised to ensure that all circuit boards are inserted properly into their respective receptacles to avoid damage to components.

To aid in the identification of specific circuit-board components, a detailed photographic layout of each circuit board is presented in Figures 6 through 19. Component symbols correspond to those in the parts list, Table 1, and the schematic diagram, Figure 20.

Input Requirements

Operation of the power conditioner requires a dc power supply capable of providing 40 to 60 volts at 35 amperes. Since operation of the power conditioner is intended to be with a solar-cell array, a fast-response,

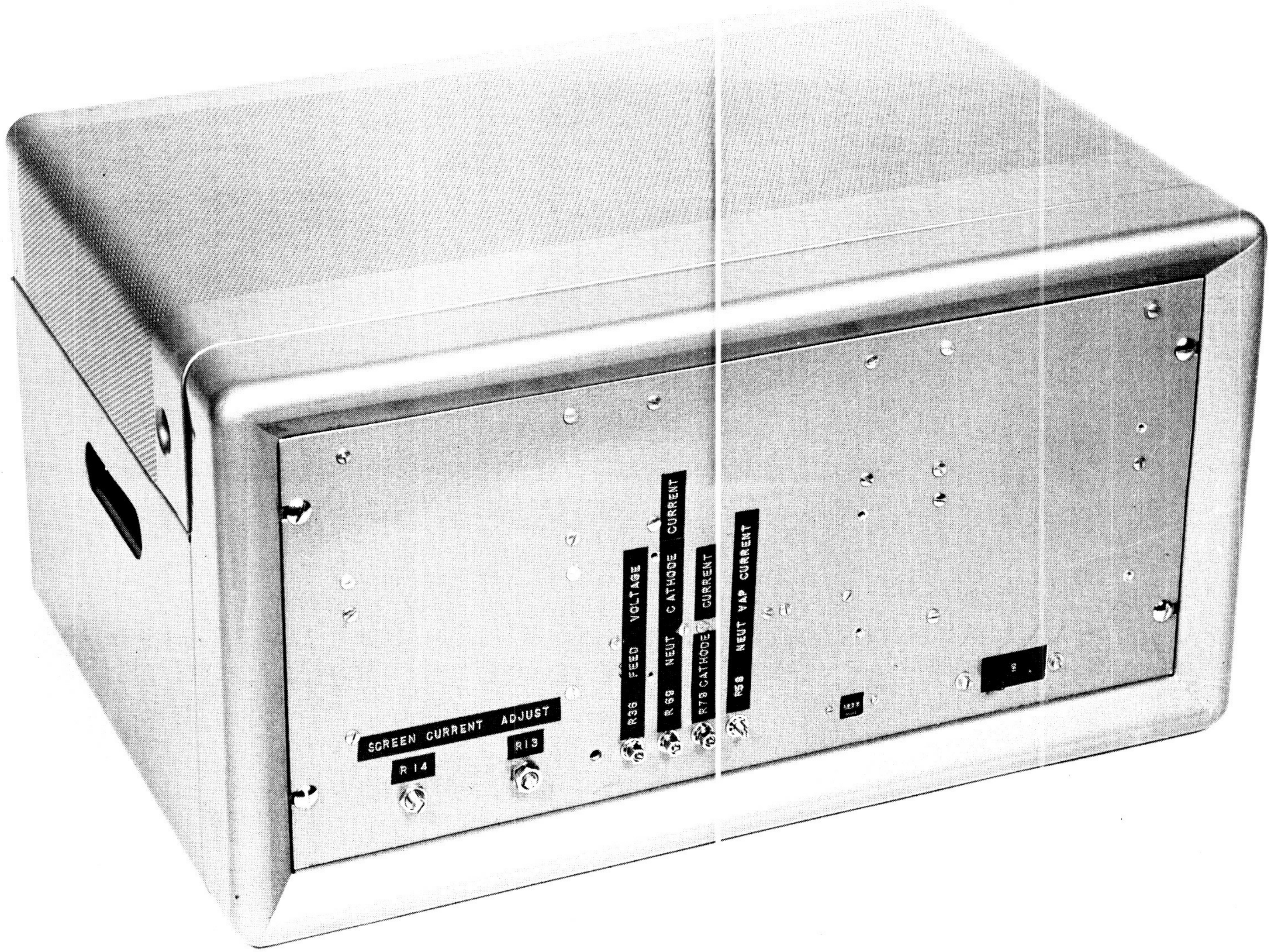


Figure 1. Front View - Power Conditioner

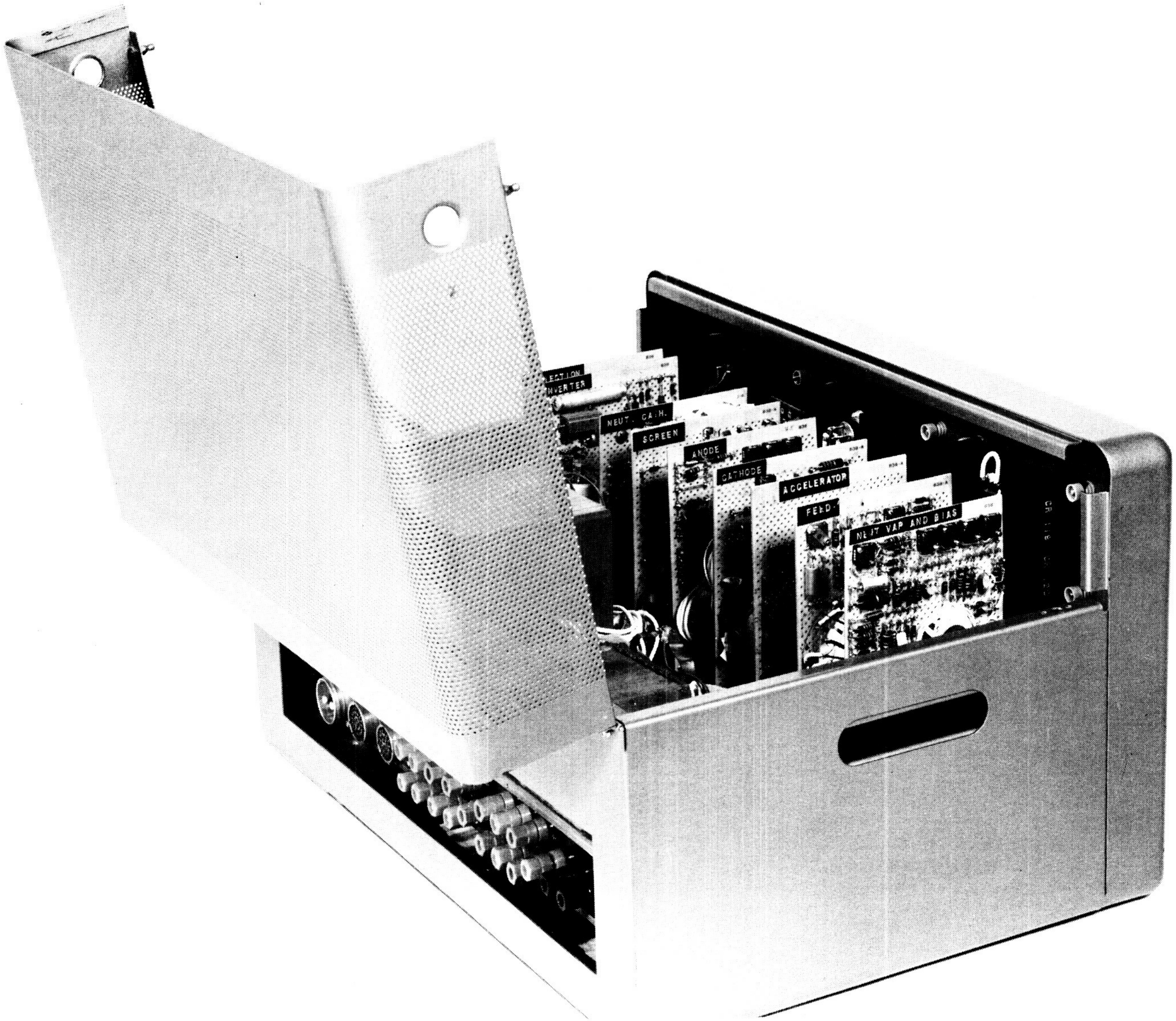


Figure 2. Side View - Power Conditioner

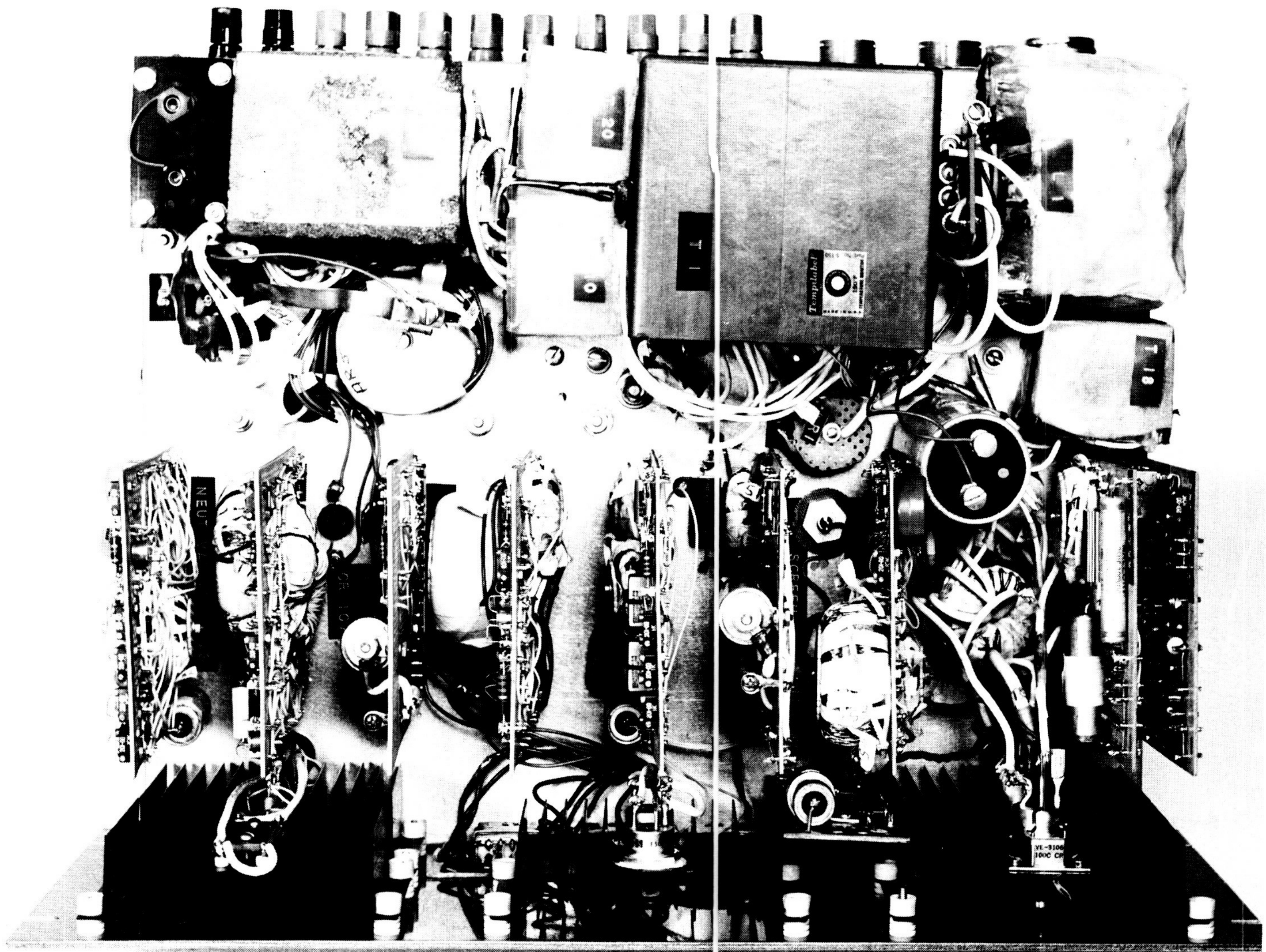


Figure 3. Top View - Power Conditioner Chassis

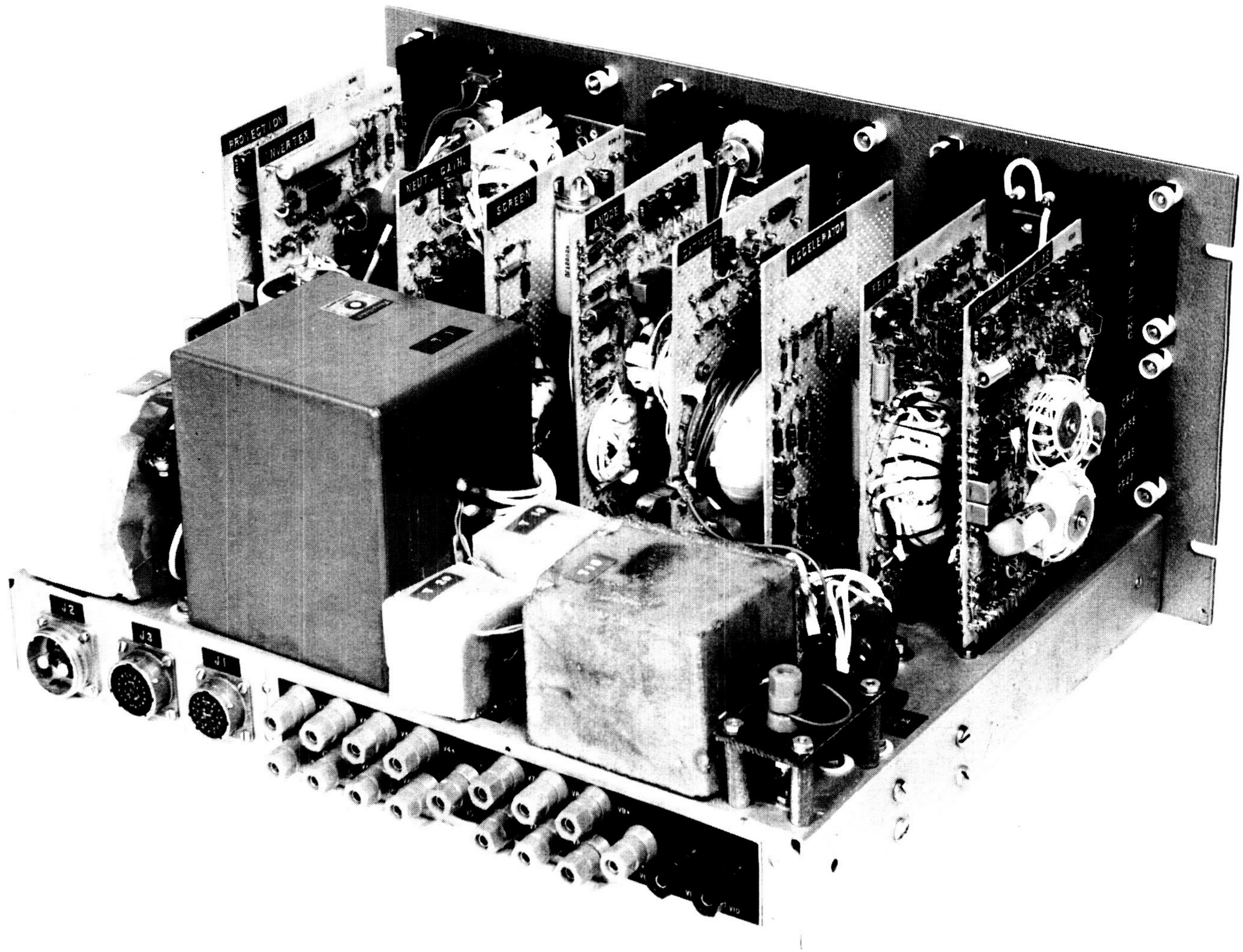


Figure 4. Rear View - Power Conditioner Chassis

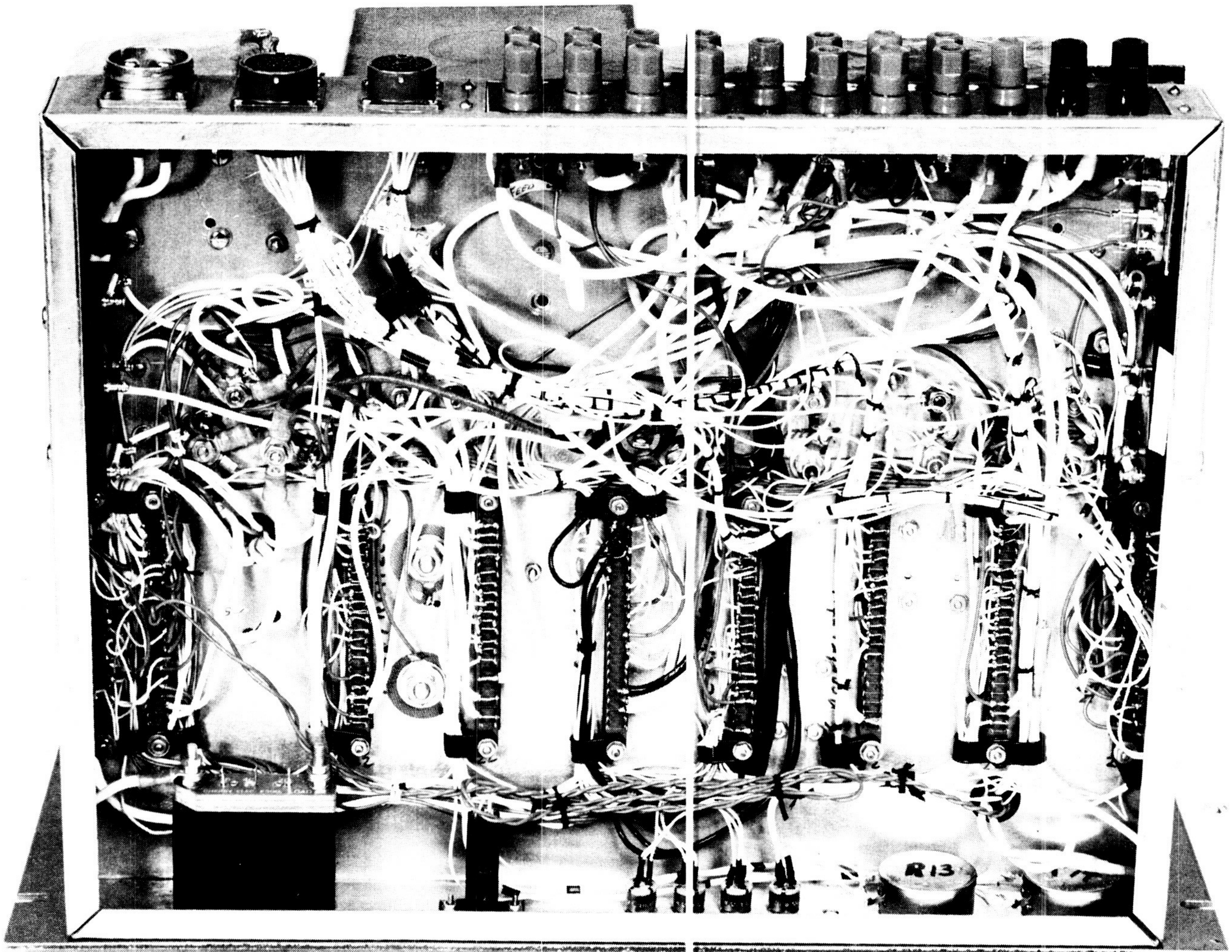


Figure 5. Bottom View - Power Conditioner Chassis

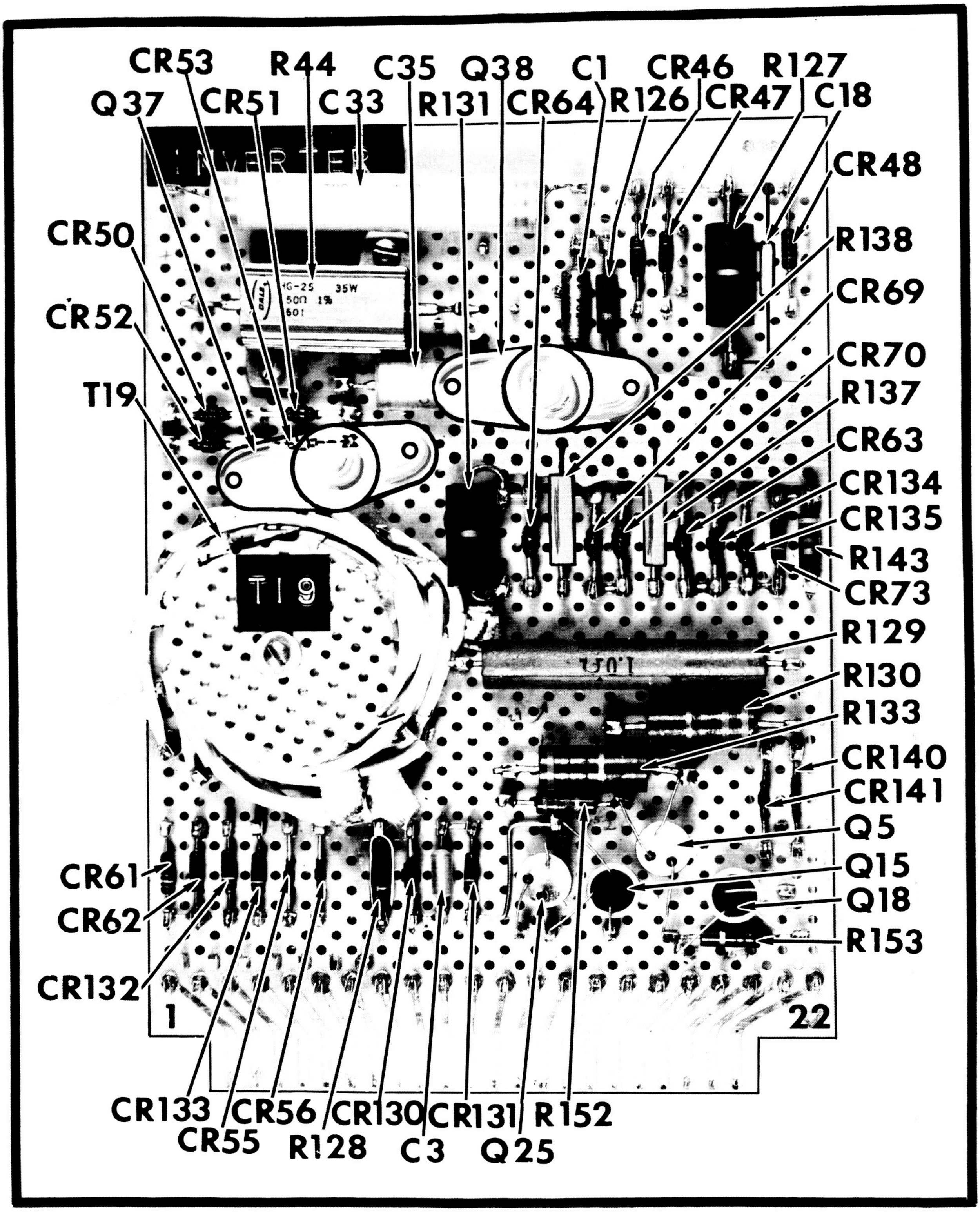


Figure 6. Inverter Circuit Board

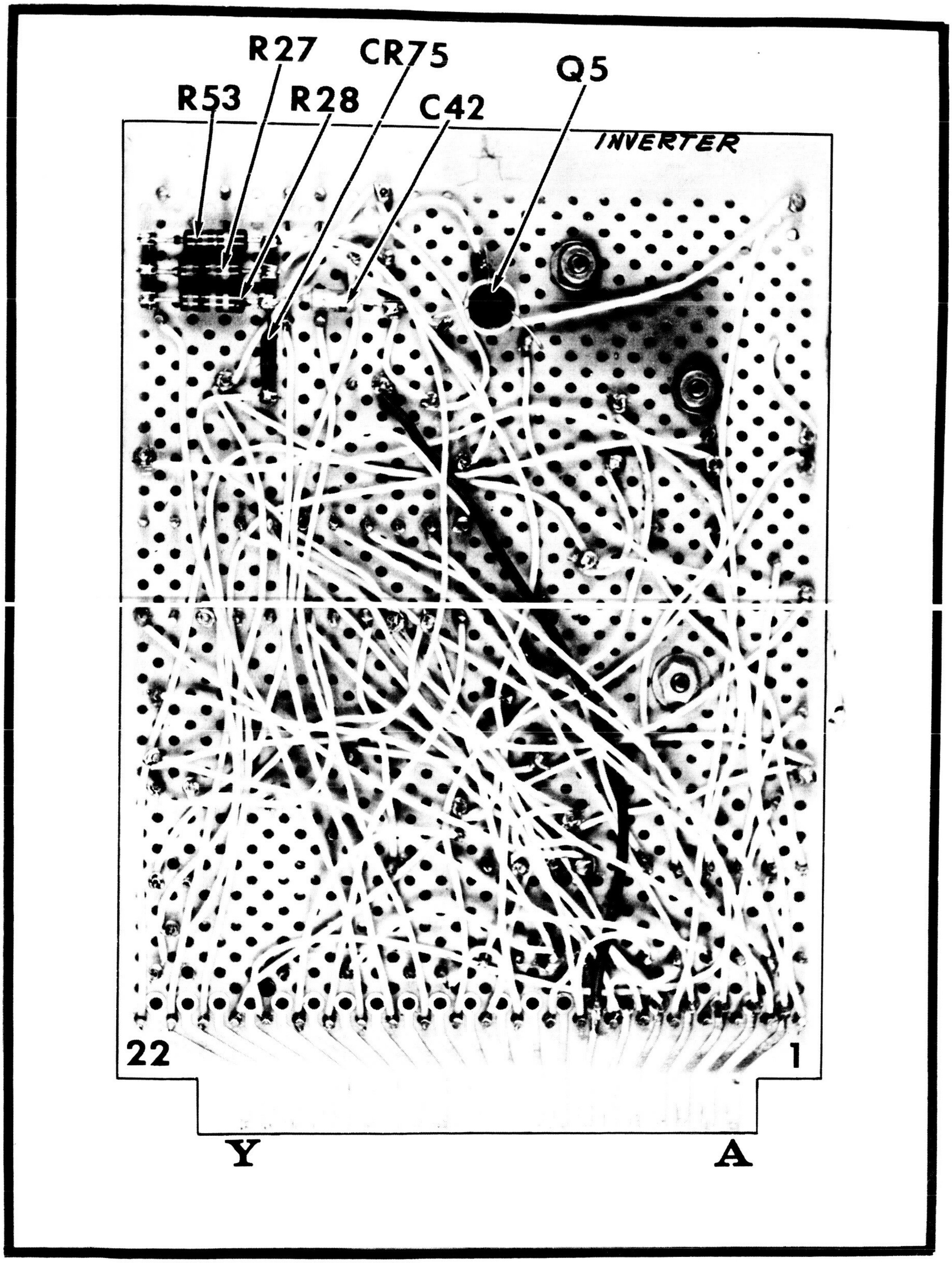


Figure 7. Inverter Circuit Board (Rear)

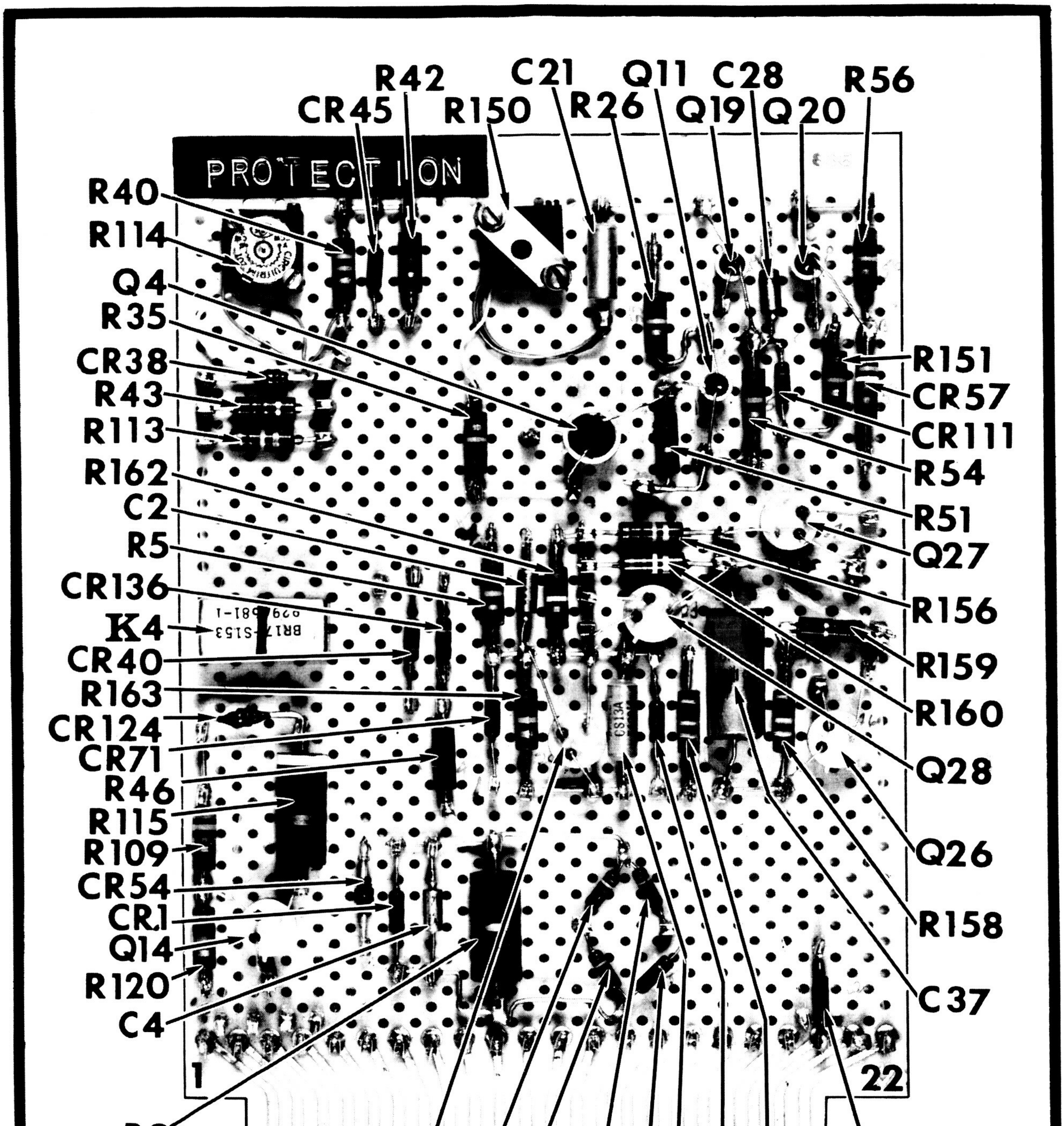


Figure 8. Protection Circuit Board

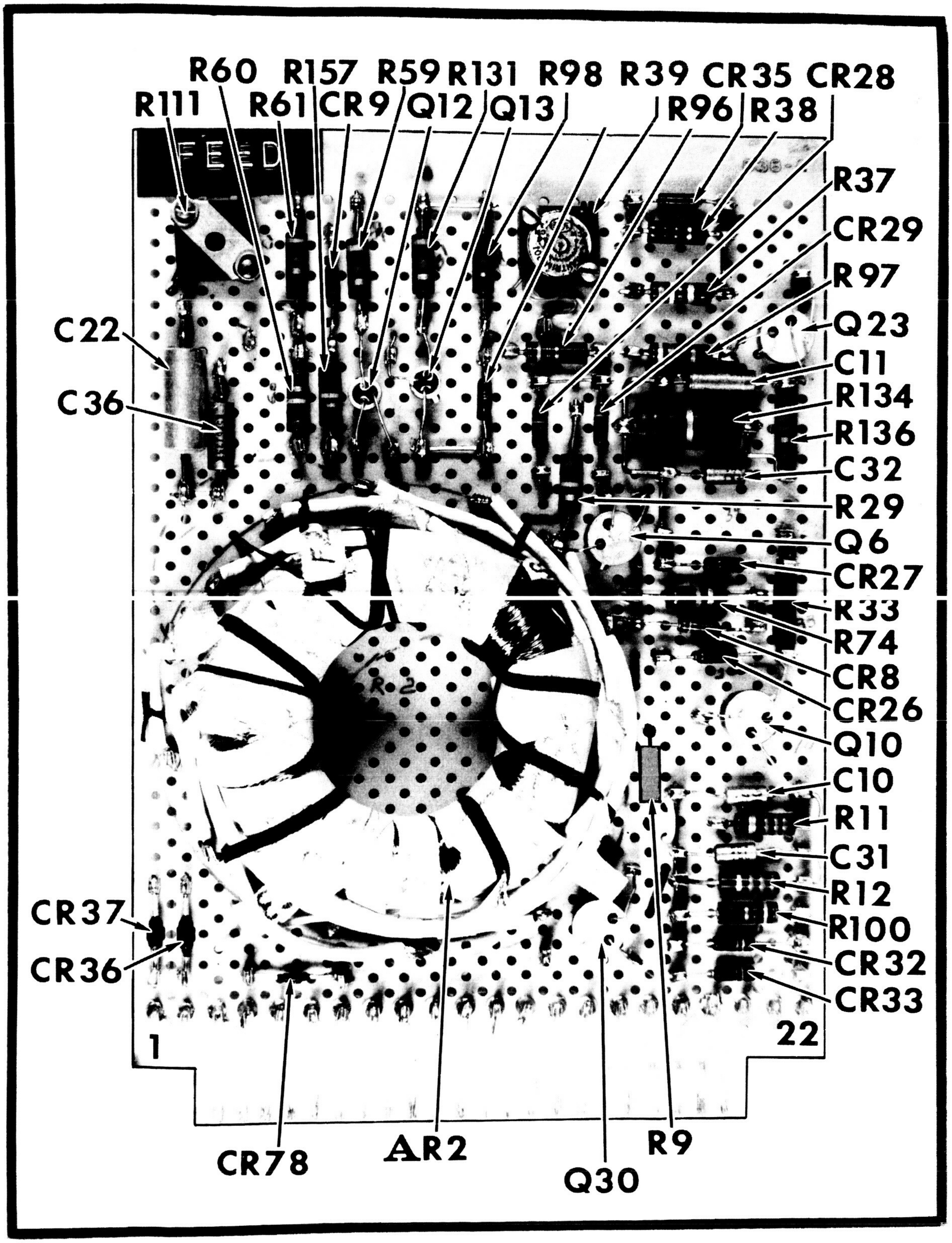


Figure 9. Feed Circuit Board

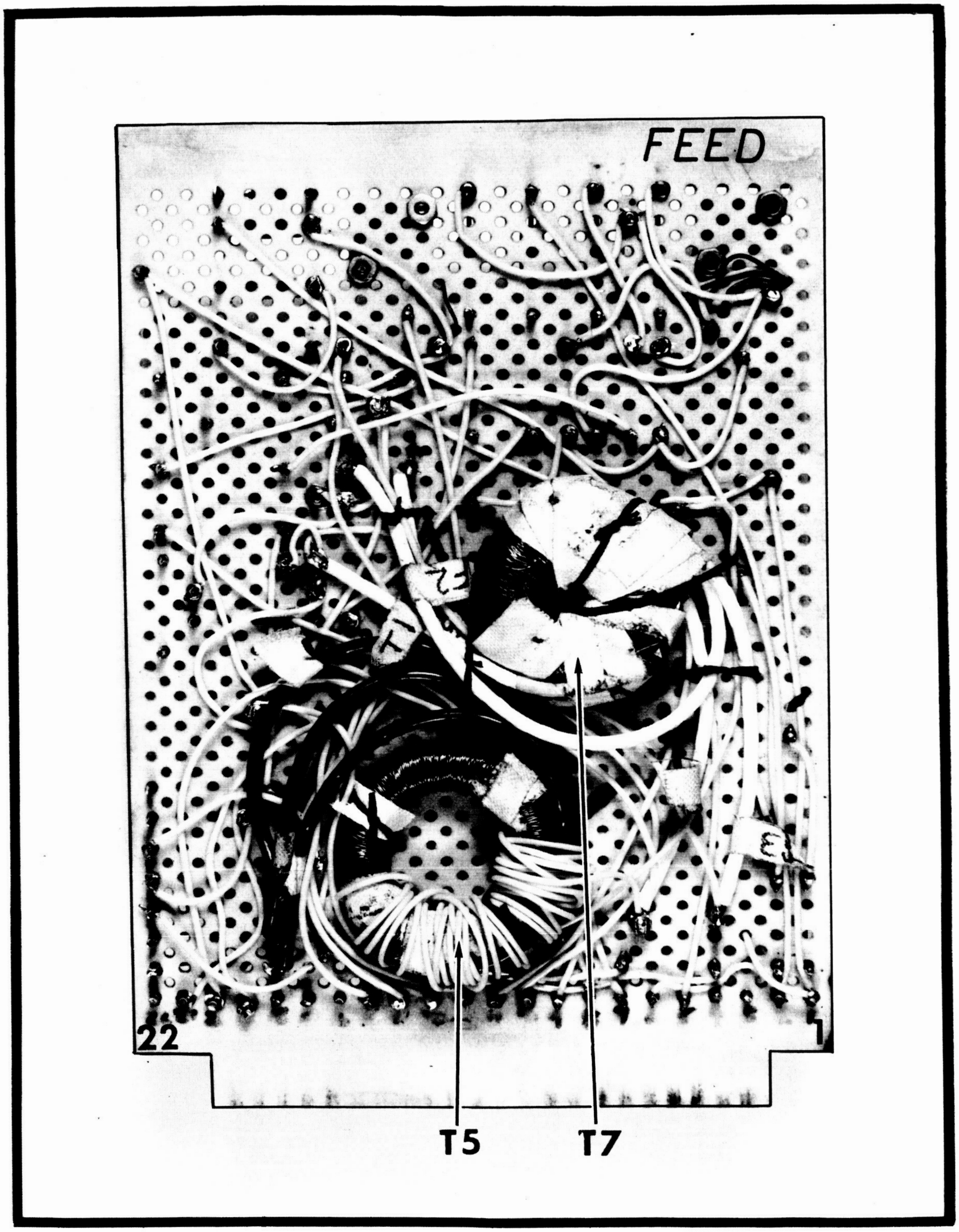


Figure 10. Feed Circuit Board (Rear)

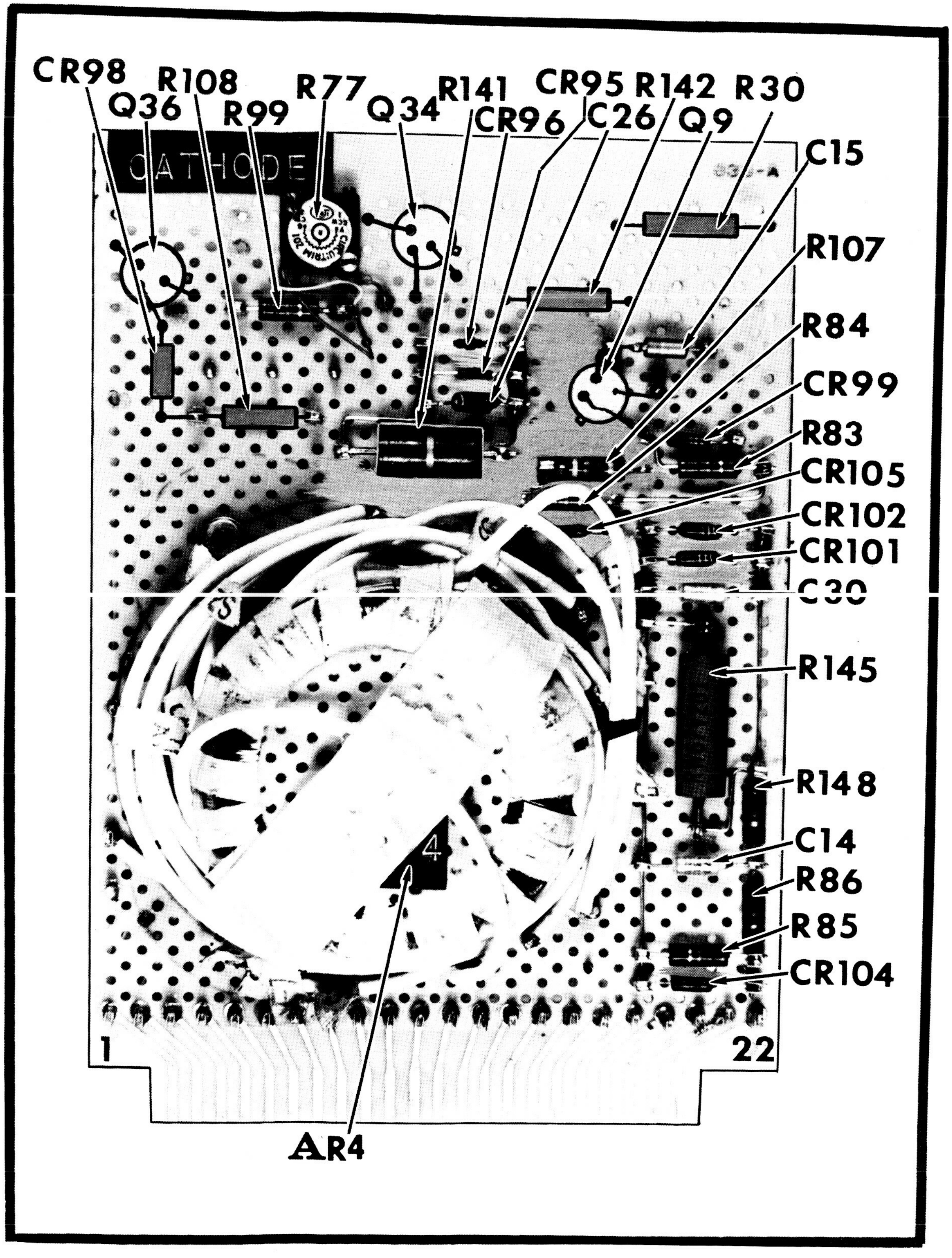


Figure 11. Cathode Circuit Board

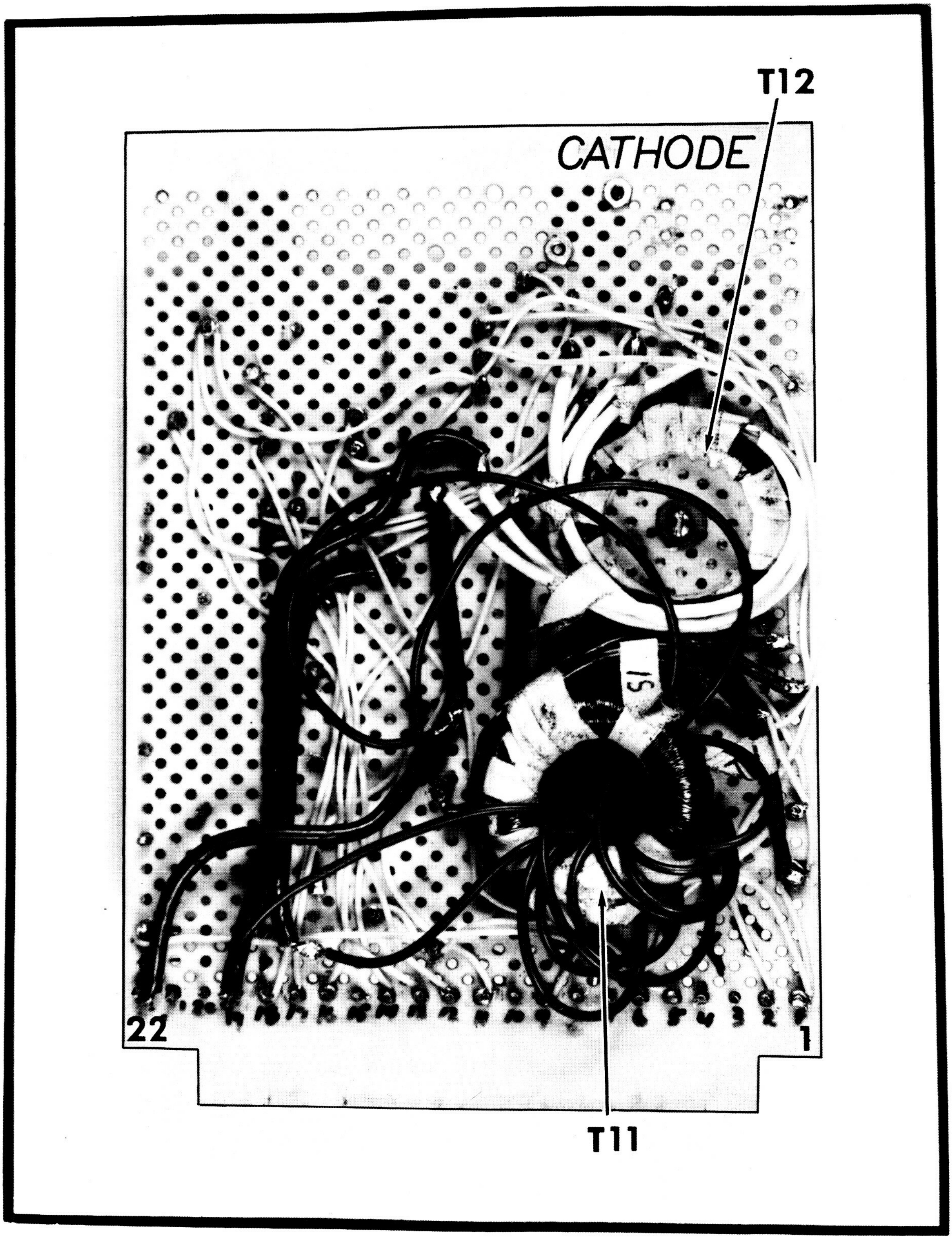


Figure 12. Cathode Circuit Board (Rear)

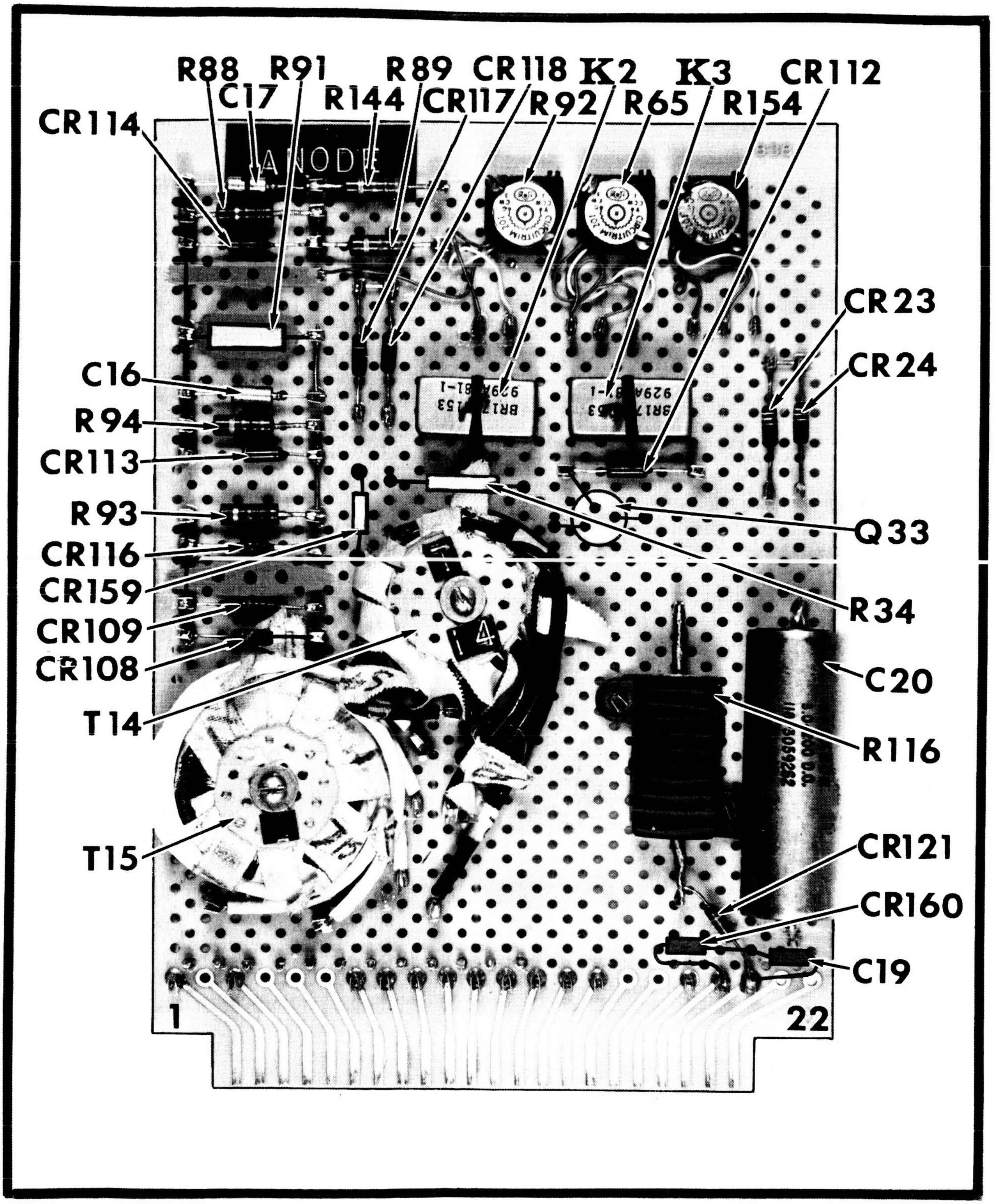


Figure 13. Anode Circuit Board

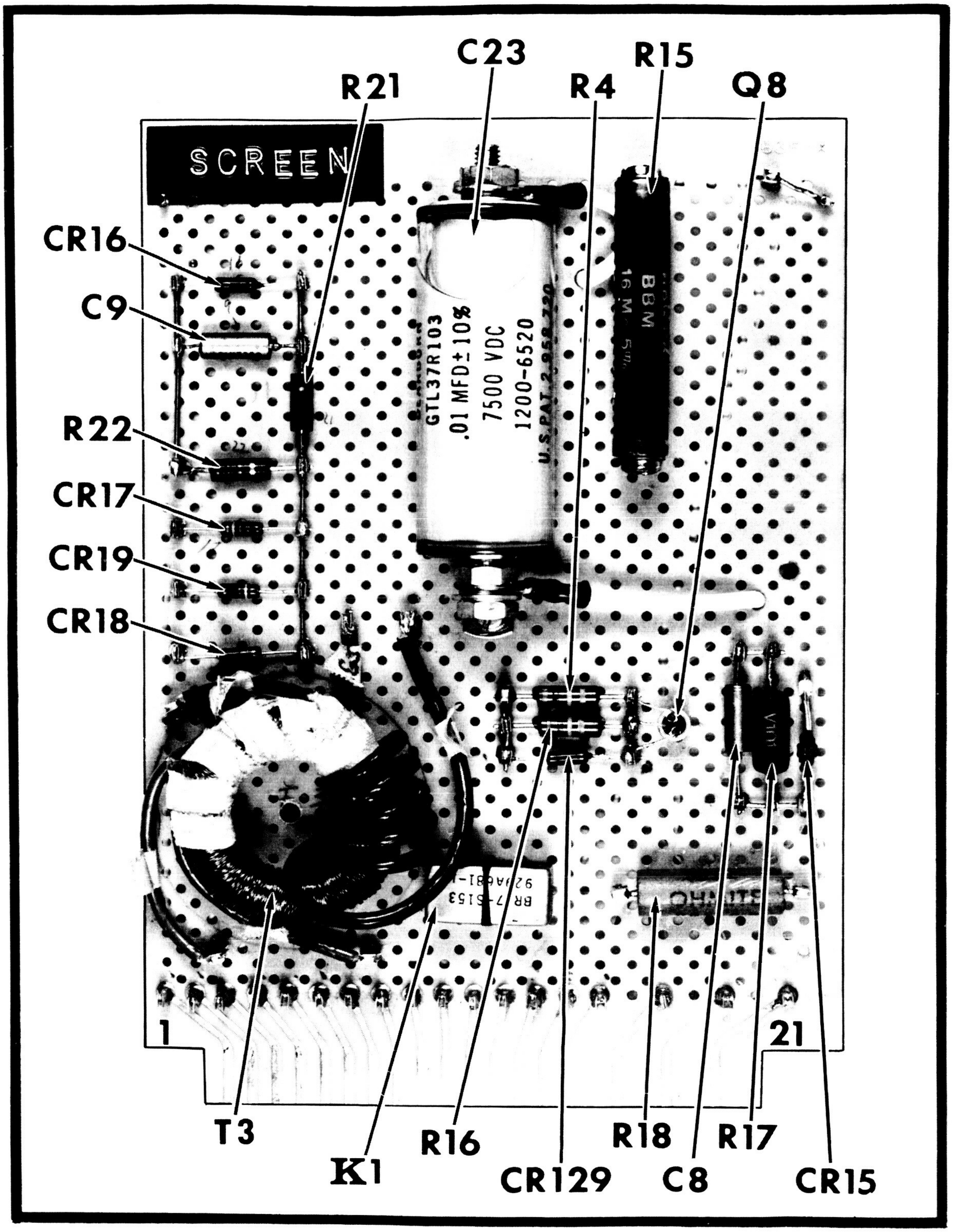


Figure 14. Screen Circuit Board

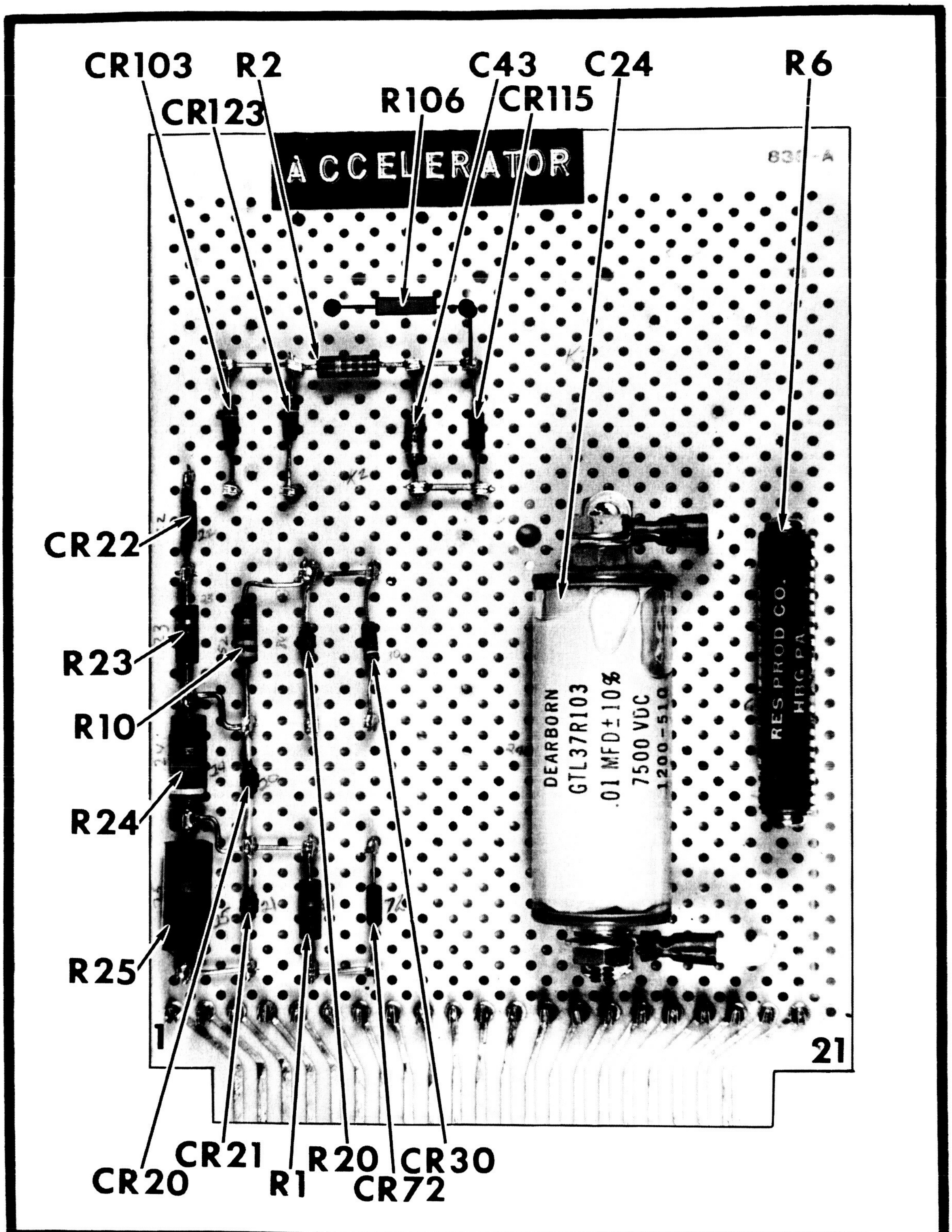


Figure 15. Accelerator Circuit Board

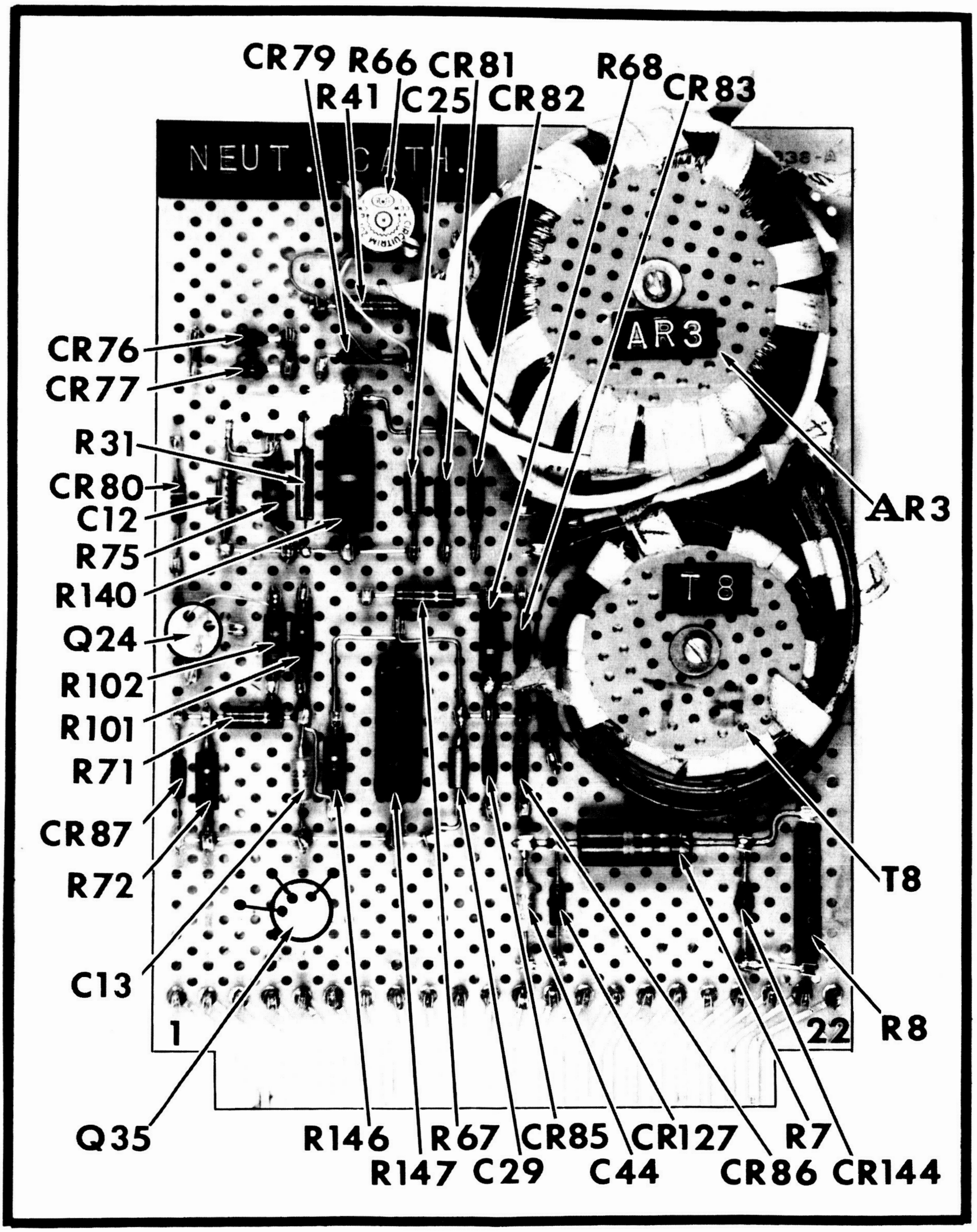


Figure 16. Neutralizer Cathode Circuit Board

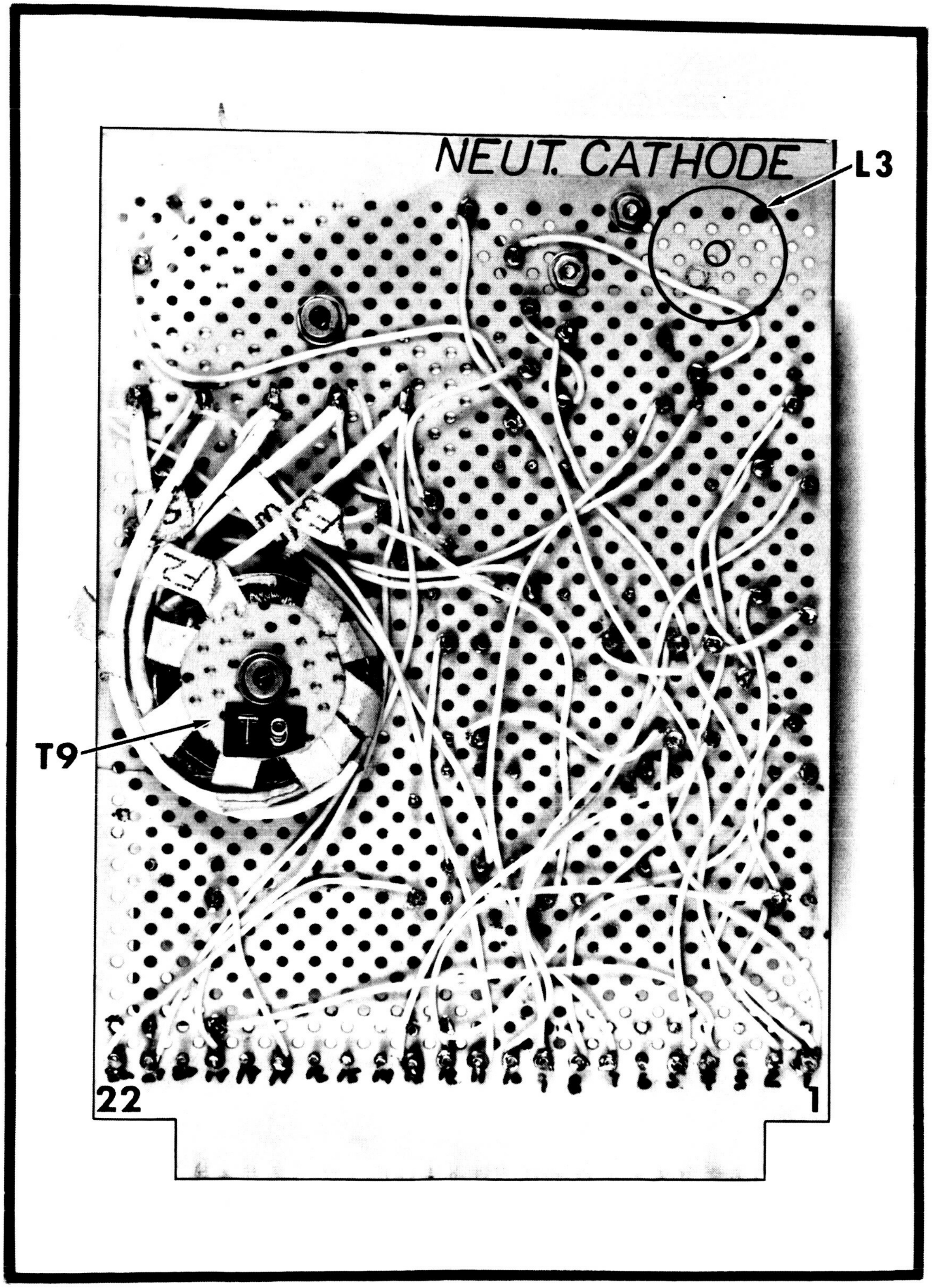


Figure 17. Neutralizer Cathode Circuit Board (Rear)

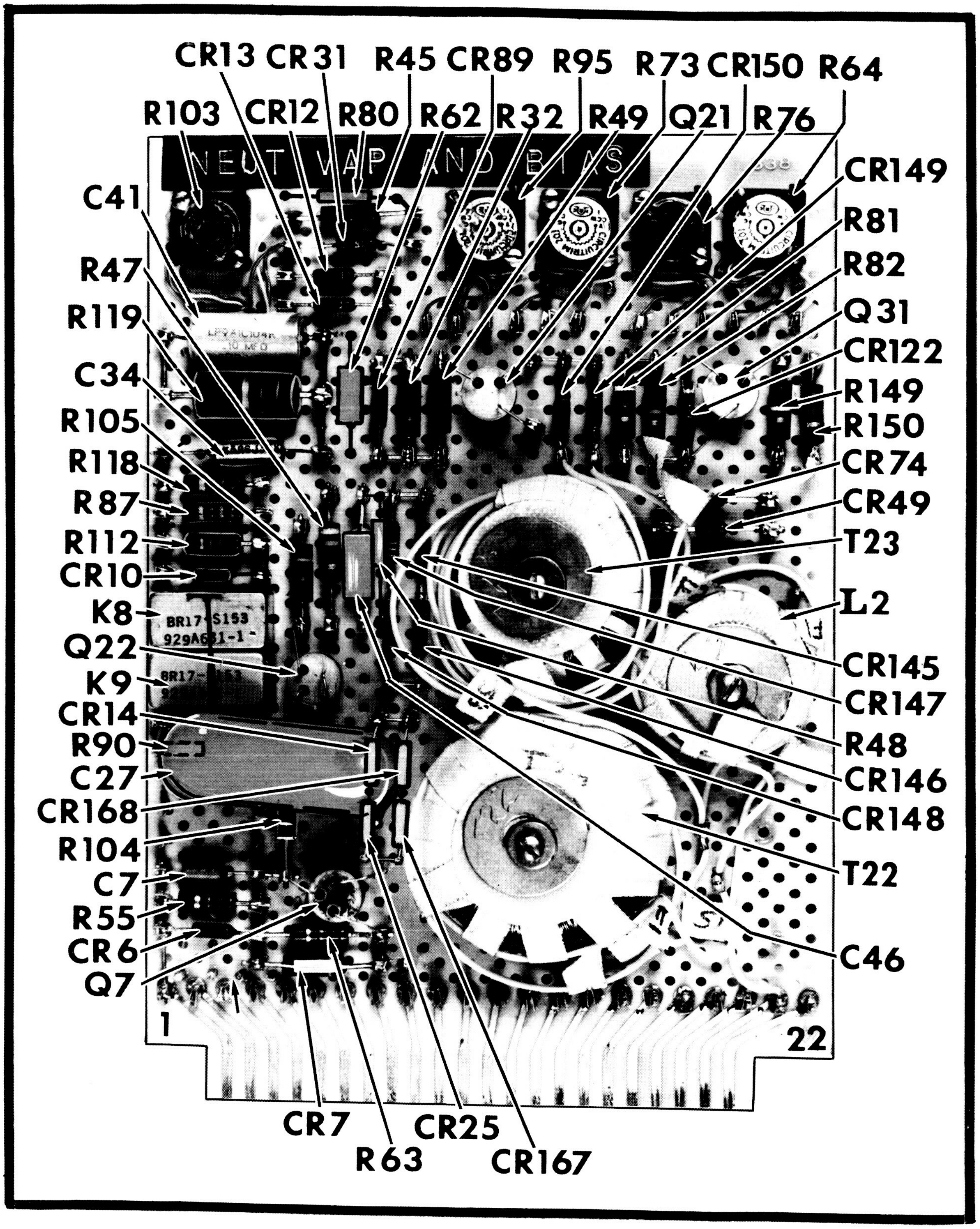


Figure 18. Neutralizer Vaporizer and Bias Circuit Board

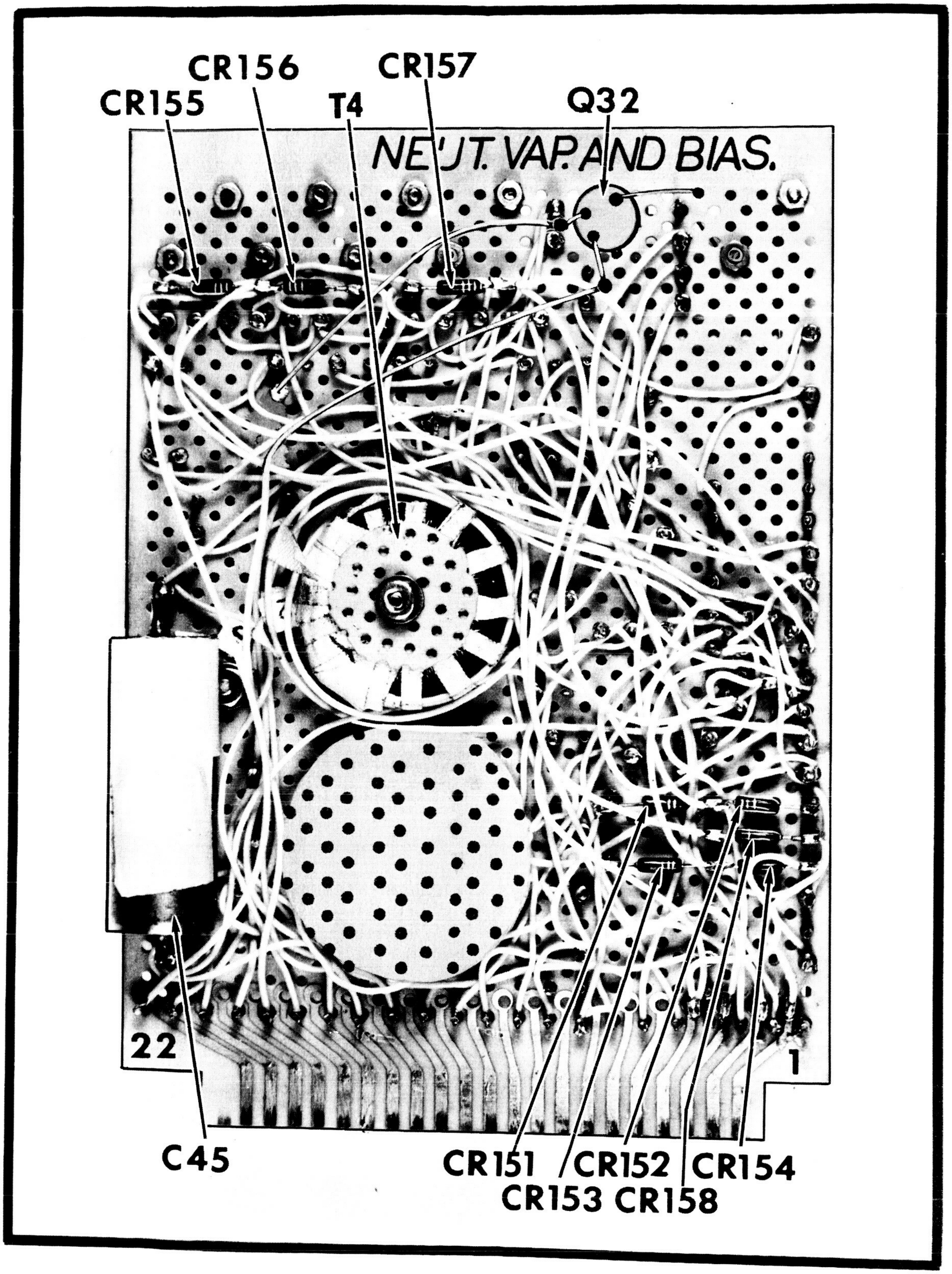


Figure 19. Neutralizer Vaporizer and Bias Circuit Board (Rear)

current-limited supply is preferred. The input filter consisting of L1, C5, and C6 minimizes the effect of the power conditioner on a supply of this type.

The power conditioner is designed to shut down when the input voltage rises above 60 volts. Reset is automatic when the power supply voltage returns to normal.

Input voltages below 40 volts cause the feed supply to turn off. When the supply voltage returns to normal, the feed supply will turn on slowly after two seconds.

The regulated outputs are controlled by magnetic amplifiers which provide pulse-width-modulated control of the output voltages.

All outputs are protected against overloads, short-circuits, and arc conditions from either of the high voltage outputs. No damage will result to the power conditioner under any load conditions.

An auxiliary 28-volt dc power supply rated at 500 milliamperes is required for the remote control panel. The panel supplies the required command signals for control of the power conditioner.

In addition, a 110-volt, 60 Hz outlet is required to operate a blower which cools the main power transistors Q1 and Q2.

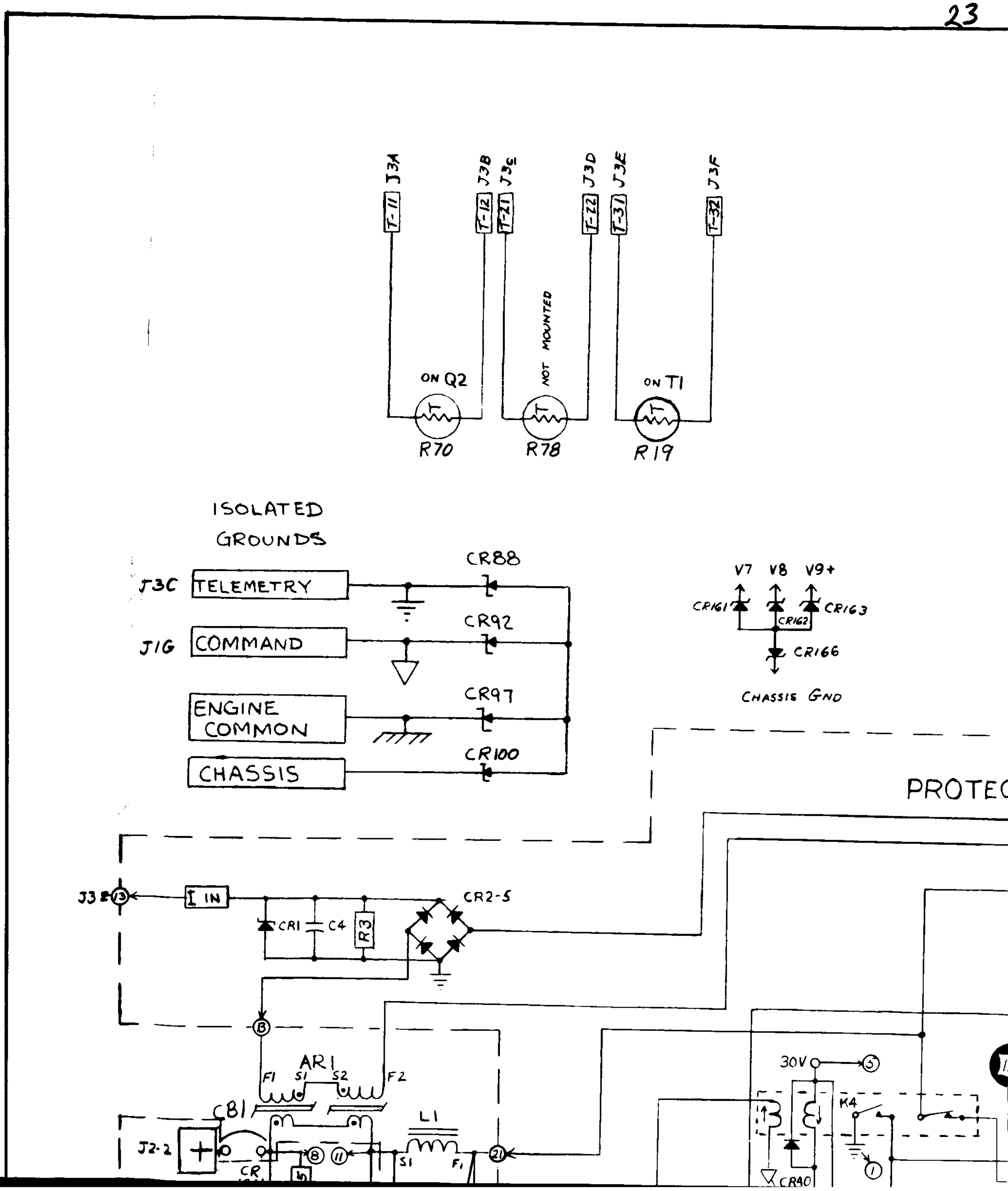
Block Diagram

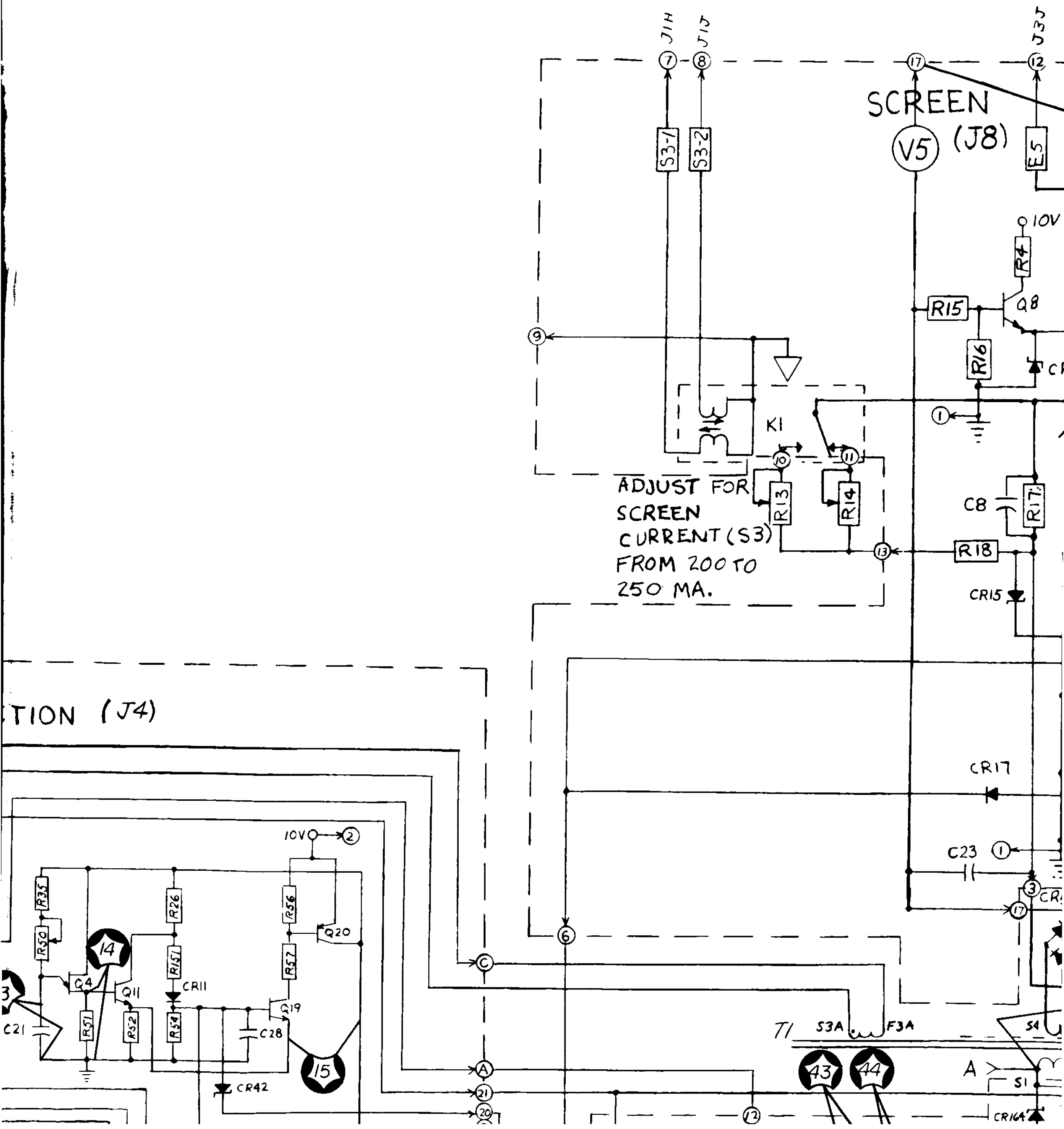
Three simplified block diagrams of the power conditioner are presented as an aid in understanding system operation. Figure 21 indicates the relationship of the various output potentials with respect to engine common. Figure 22 shows the flow of power through the unit, while Figure 23 is a signal flow diagram showing the individual control loops.

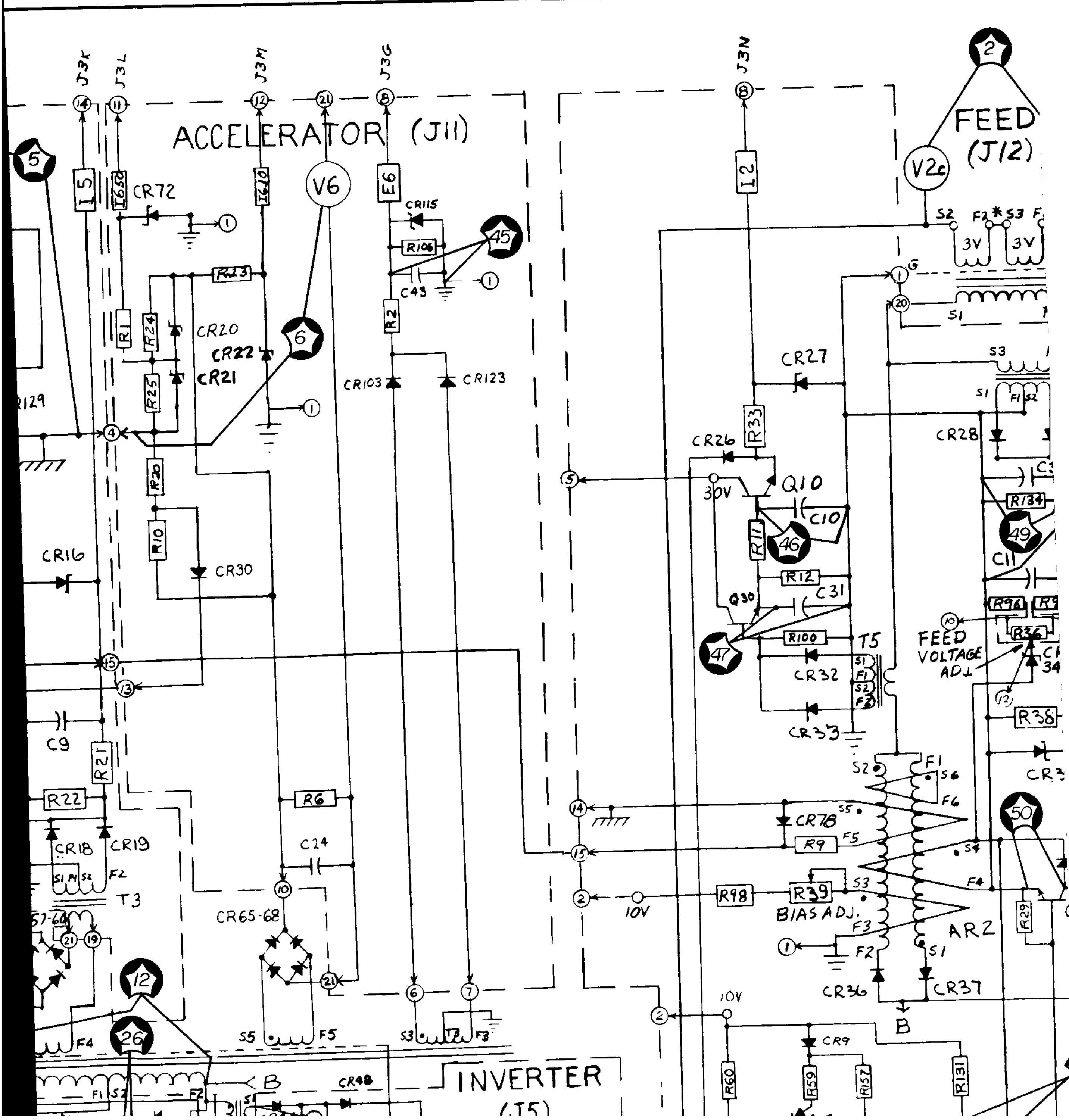
THEORY OF OPERATION

Basic Operating Theory

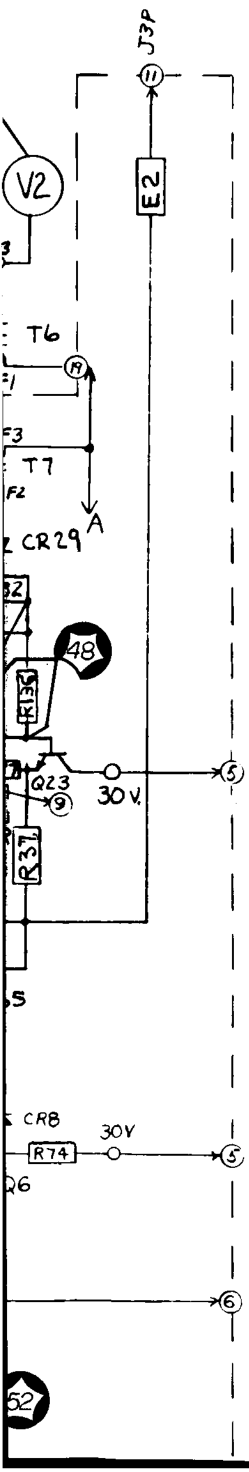
Inherent to the basic operation of the power conditioner is the magnetic oscillator consisting of transistors Q16, Q17, and associated components, and the power amplifier consisting of transistors Q1, Q2, and

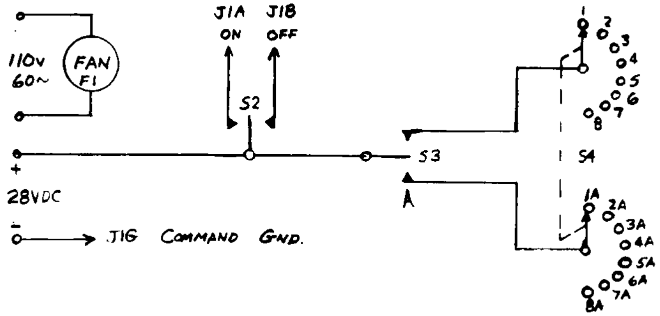

J3A
J3B
J3C
J3D
J3E
J3F
T-11
T-12
T-21
T-22
T-31
T-32
NOT MOUNTED
ON Q2
ON T1
R70
R78
R19
ISOLATED GROUNDS
J3C
TELEMETRY
J1G
COMMAND
ENGINE COMMON
CHASSIS
CR88
CR92
CR97
CR100
V7 V8 V9+
CR161
CR162
CR163
CR166
CHASSIS GND
PROTEC
J3
I IN
CR1
C4
R3
CR2-5
AR1
F1
S1
S2
F2
CB1
L1
J2-2
CR
30V
K4
CR40


J1H
J1J
J3J
SCREEN
V5
(J8)
S3-1
S3-2
E5
10V
R4
R15
Q8
R16
K1
ADJUST FOR SCREEN CURRENT (S3) FROM 200 TO 250 MA.
R13
R14
C8
R17
R18
CR15
TION (J4)
CR17
C23
10V
R35
R50
R26
R56
Q20
R151
R57
Q4
Q11
CR11
Q19
C21
R51
R52
R54
C28
CR42
T1
S3A
F3A
A
S1
S4
CR164


ACCELERATOR (J11)
FEED (J12)
INVERTER (T5)
J3K
J3L
J3M
J3G
J3N
V6
V2c
Q10
Q30
T3
T5
AR2
CR72
CR20
CR22
CR21
CR16
CR30
CR18
CR19
CR65-68
CR115
CR103
CR123
CR27
CR26
CR28
CR32
CR33
CR78
CR36
CR37
CR9
CR48
R23
R24
R25
R20
R10
R1
R21
R22
R6
R106
R2
R33
R11
R12
R100
R9
R98
R39
R134
R96
R36
R38
R29
R60
R59
R157
R131
C43
C9
C24
C10
C31
C11
L5
L2
I65G
I610
E6
30V
10V
3V
BIAS ADJ.
FEED VOLTAGE ADJ.
B

-24-3





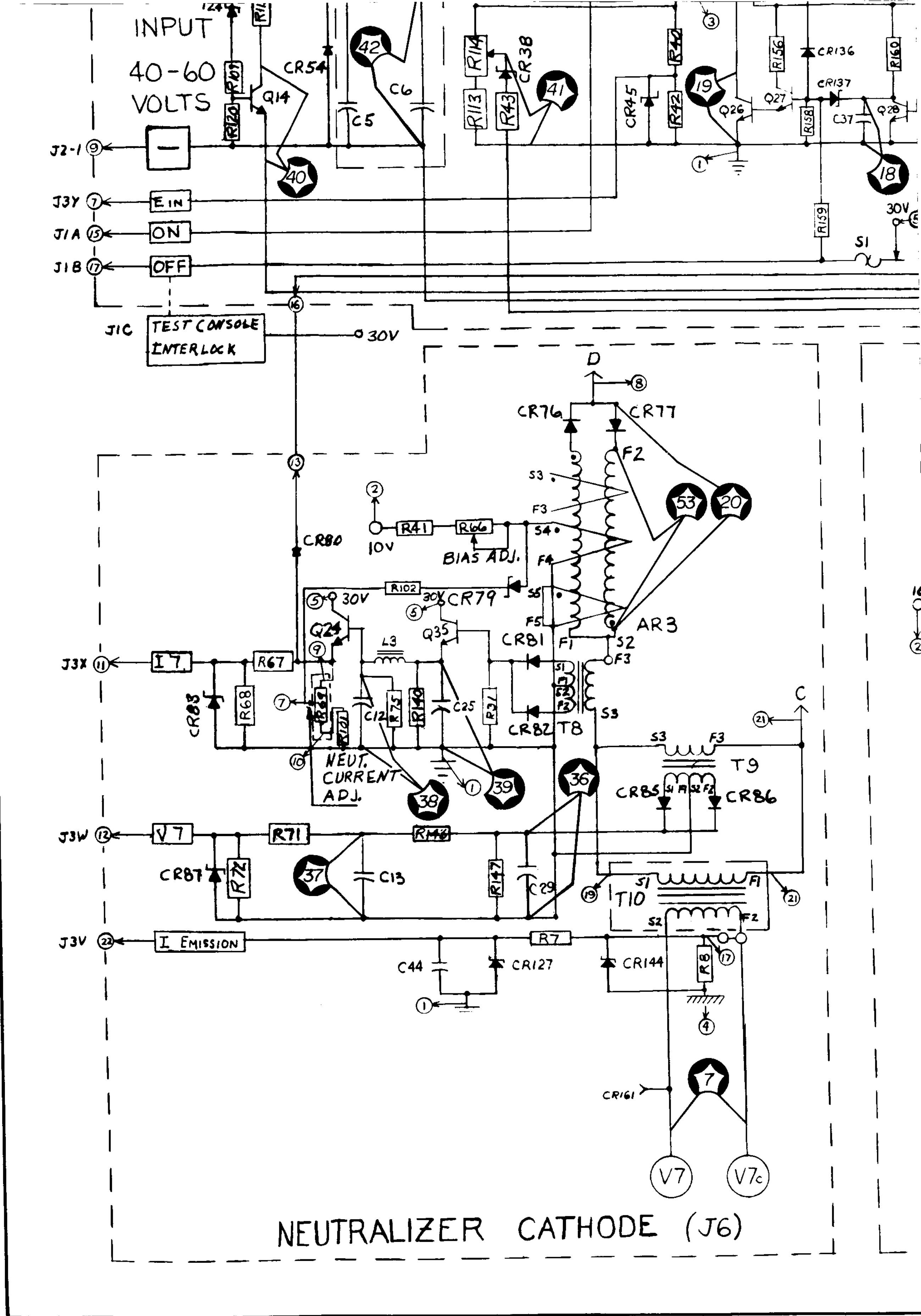
S4 POSITION INDEX

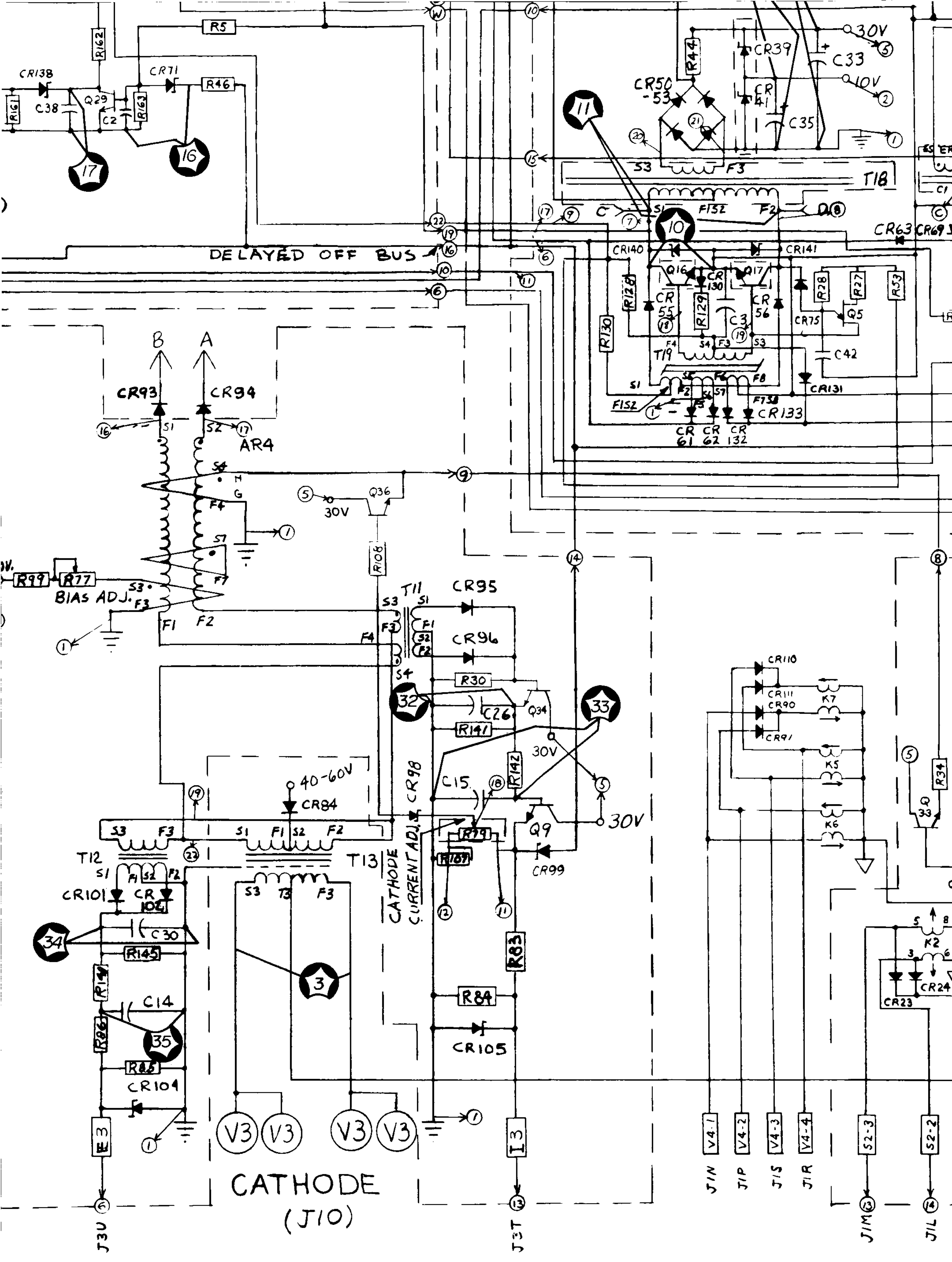
1	S3-1	J1H
2	S3-2	J1J
3	S2-1	J1K
4	S2-2	J1L
5	S2-3	J1M
6		
7		
8		

1A	V4-1	J1N
2A	V4-2	J1P
3A	V4-3	J1S
4A	V4-4	J1R
5A	V9-1	J1T
6A	V9-2	J1U
7A	V9-3	J1V
8A	V9-4	J1g

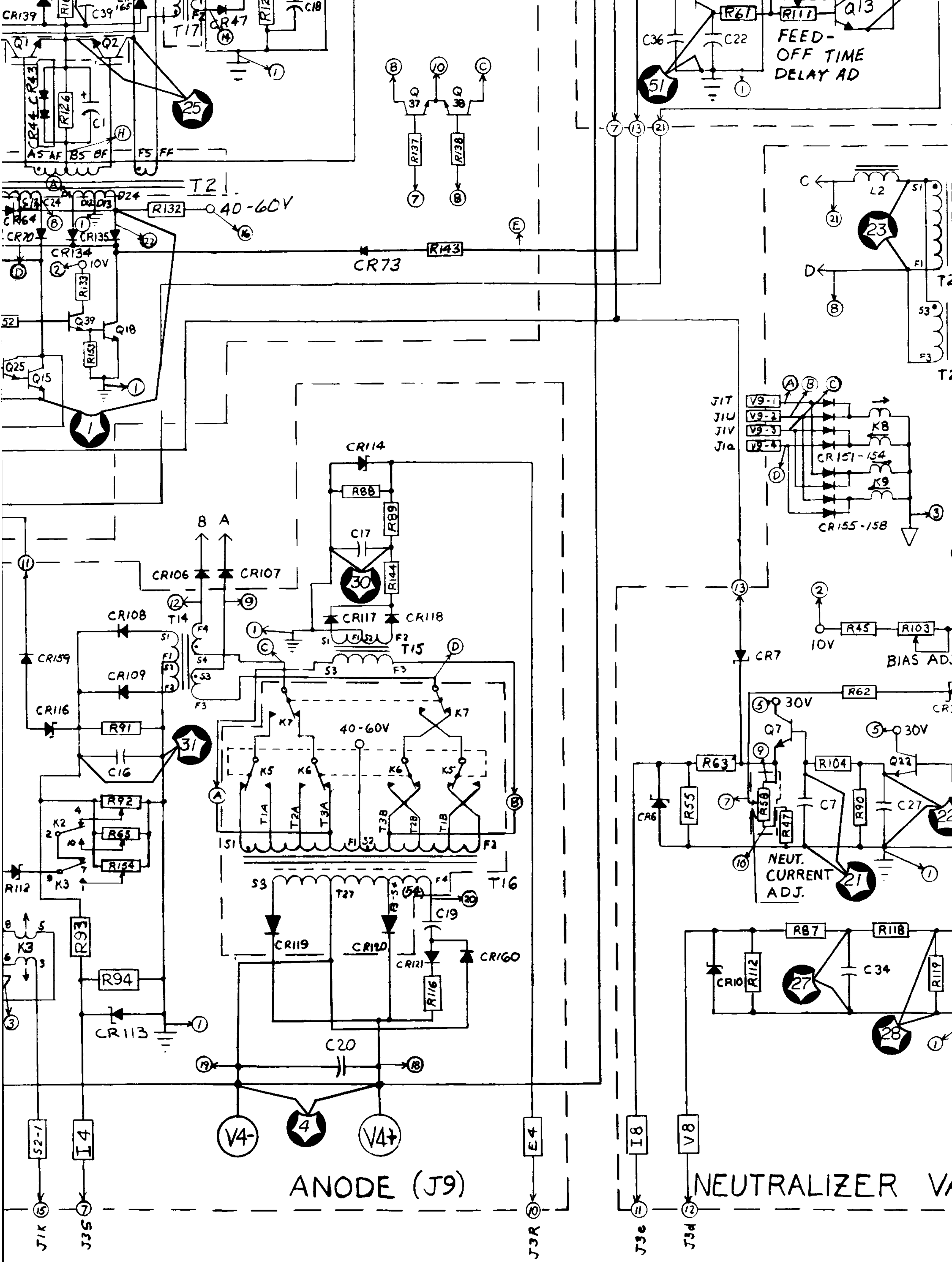
•SYMBOL•

 =TEST POINTS


INPUT
40-60
VOLTS
J2-1
J3Y
J1A
J1B
J1C
E IN
ON
OFF
TEST CONSOLE
INTERLOCK
30V
Q14
CR54
C5
C6
R113
R114
R43
CR38
CR45
R42
Q26
Q27
CR136
CR137
R156
R158
R159
R160
C37
Q28
S1
D
C
CR76
CR77
F2
S3
F3
S4
F4
S5
F5
F1
S2
AR3
BIAS ADJ.
10V
R41
R66
R102
CR79
CR80
CR81
CR82
T8
Q24
Q35
L3
R67
R68
CR83
J3X
I7
C12
R75
R140
C25
R31
NEUT.
CURRENT
ADJ.
T9
CR85
CR86
J3W
V7
R71
R146
CR87
R72
C13
R147
C29
T10
J3V
I EMISSION
R7
C44
CR127
CR144
R8
CR161
V7c
NEUTRALIZER CATHODE (J6)



R162
R5
CR138
CR71
R46
R161
C38
Q29
C2
R163
17
16
R44
CR39
30V
C33
10V
CR50-53
CR41
C35
11
S3
F3
T18
DELAYED OFF BUS
CR63
CR69
F1S2
F2
10
CR140
CR141
Q16
Q17
CR130
R128
CR55
R129
C3
CR56
R28
R27
R53
Q5
CR75
R130
C42
T19
CR131
F1S2
F7S8
CR133
CR61
CR62
CR132
B
A
CR93
CR94
AR4
Q36
30V
R108
R99
R77
BIAS ADJ.
T11
CR95
CR96
R30
C26
Q34
32
33
R141
30V
R142
C15
CR98
40-60V
CR84
T12
T13
CR101
CR104
C30
34
R145
R144
C14
R86
35
R85
CR104
CR79
R107
CATHODE CURRENT ADJ.
Q9
CR99
30V
R83
R84
CR105
3
E3
V3
V3
V3
V3
I3
CATHODE
(J10)
J3U
J3T
CR110
CR111
CR90
CR91
K7
K5
K6
R34
Q33
K2
CR23
CR24
V4-1
V4-2
V4-3
V4-4
J1N
J1P
J1S
J1R
S2-3
S2-2
J1M
J1L



FEED-OFF TIME DELAY AD
40-60V
CR73
R143
ANODE (J9)
NEUTRALIZER VA
BIAS ADJ.
NEUT. CURRENT ADJ.
30V
10V
T14
T15
T16
T2
J1K
J3S
J3R
J3e
J3d

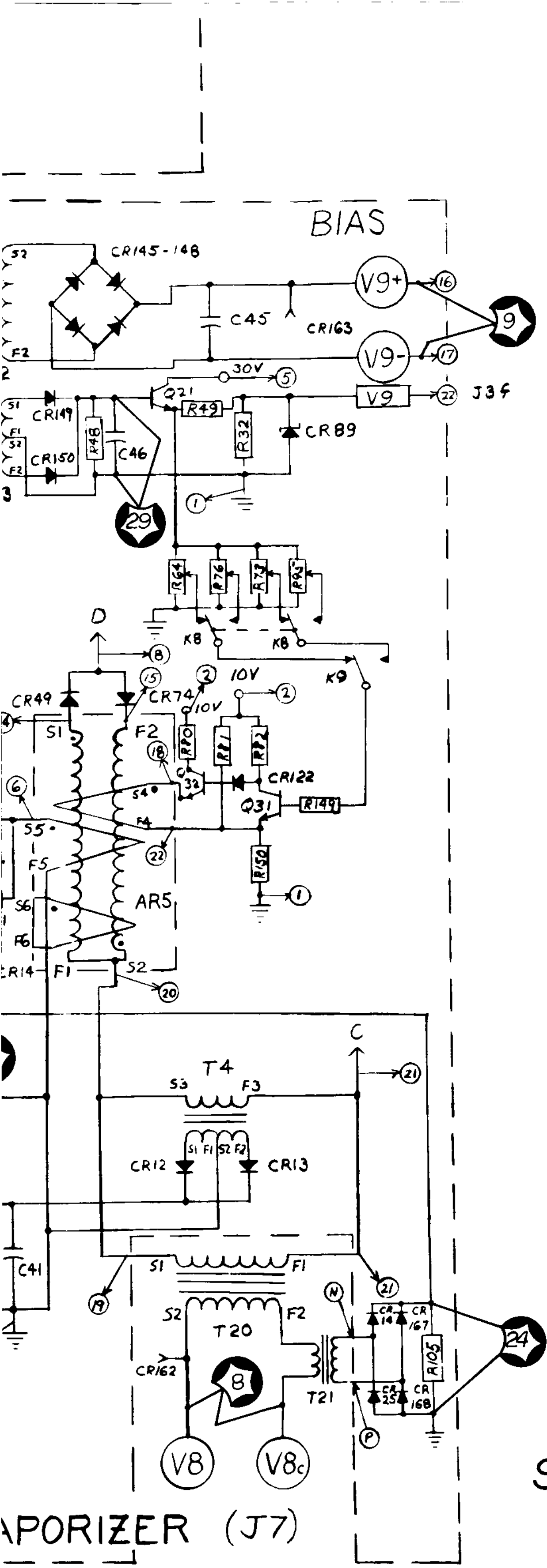


FIGURE 20.
SCHEMATIC DIAGRAM

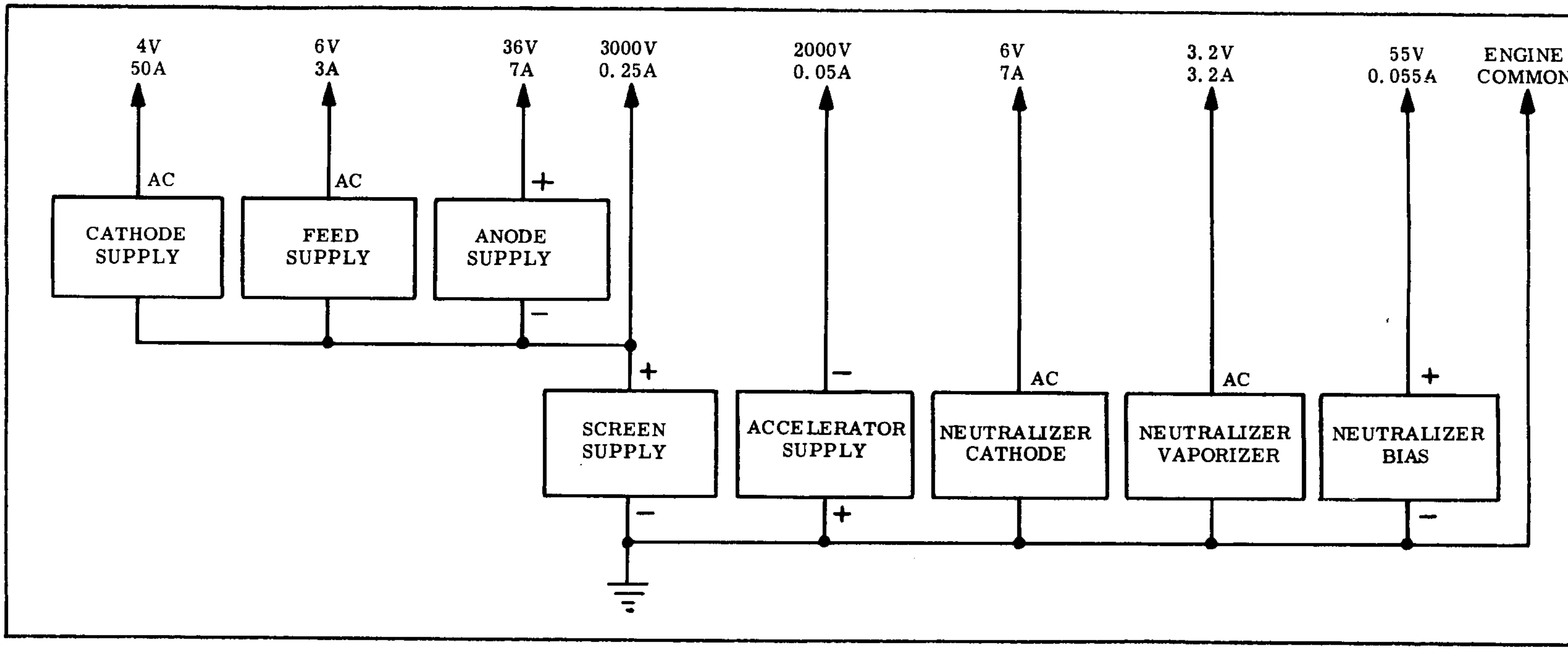


FIGURE 21. Power Conditioner Output Potential Relationships

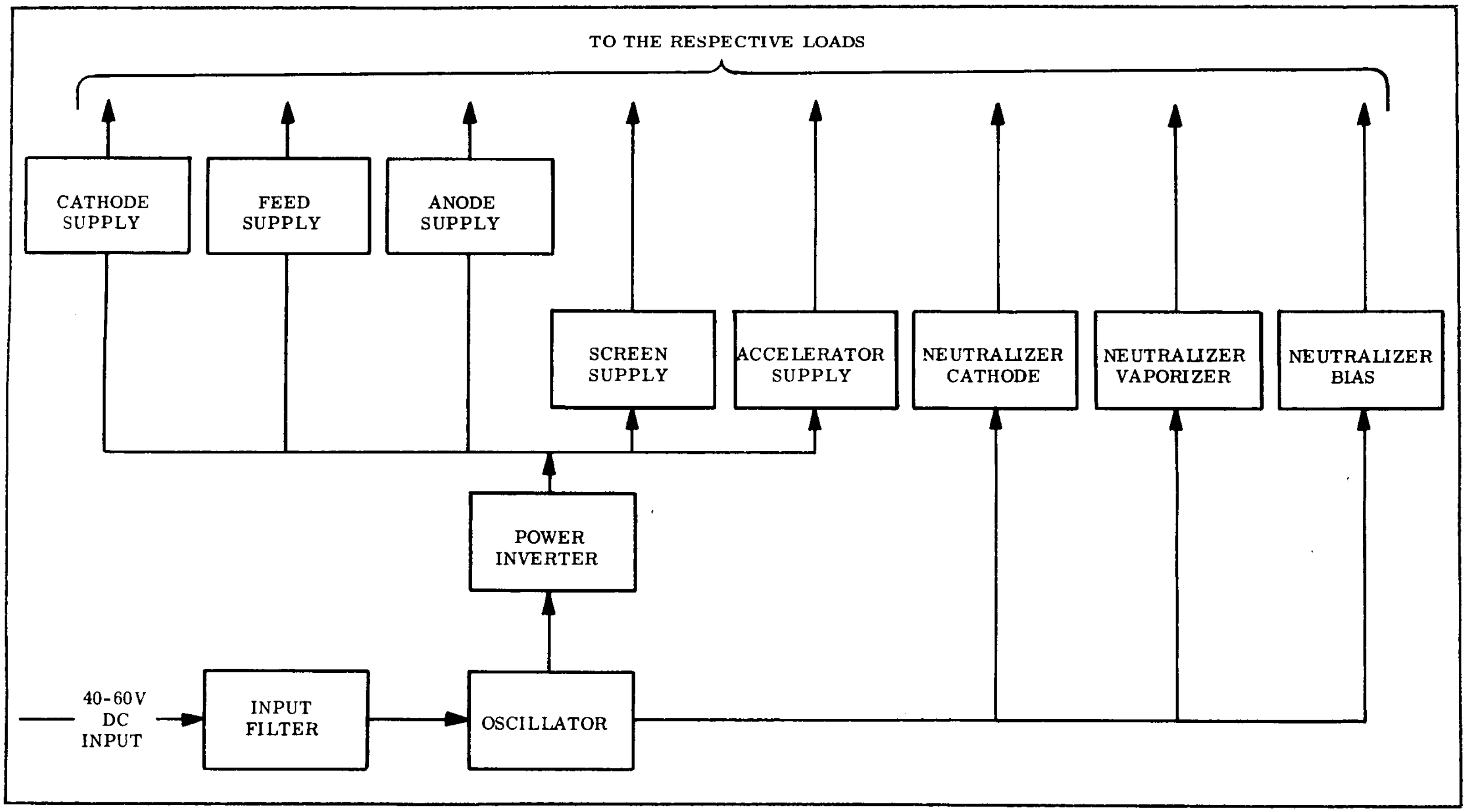


FIGURE 22. Power Conditioner Power Flow

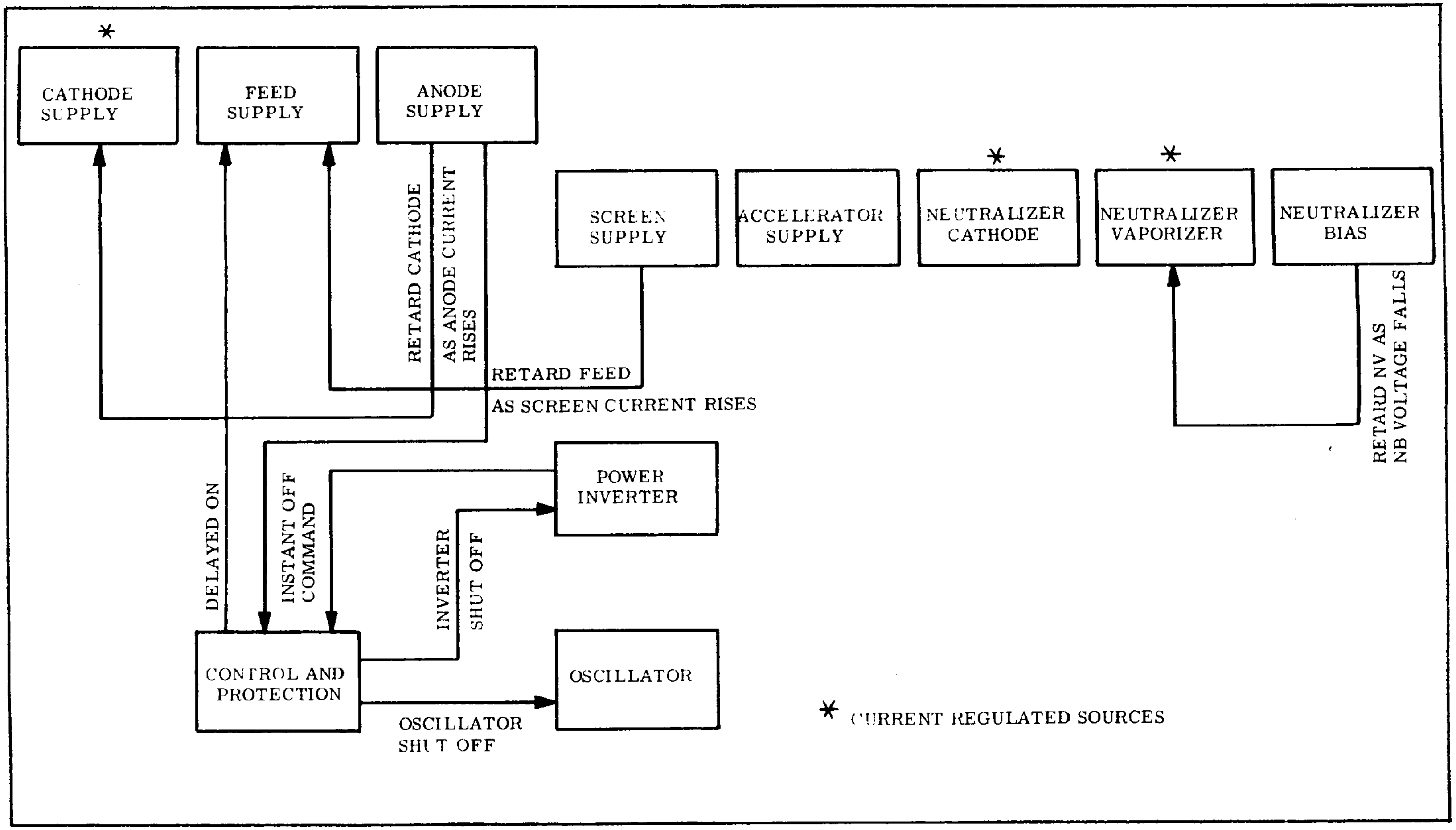


FIGURE 23. Power Conditioner Control Loops

associated components.

The magnetic oscillator provides a 2-kHz, 90-volt squarewave with an applied input voltage of 45 volts. This squarewave is present at points C and D in Figure 20 and provides input power to the three neutralizer circuits. The squarewave exists at all times while the power conditioner is in operation.

The power amplifier provides a similar 2-kHz, 90-volt squarewave under nominal input conditions. This squarewave is present at points A and B in Figure 20 and provides input power to the cathode, anode, and feed circuits. The squarewave is present at all times during power conditioner operation except during periods of instant-off shutdown.

Input power to the screen and accelerator circuits is obtained via secondary windings on high voltage transformer T1.

DC Outputs. - The anode, screen, accelerator, and neutralizer bias circuits provide dc outputs to the load. The volt-ampere characteristics of these supplies are presented in Figures 24 through 30. All of these circuits full-wave rectify the ac squarewave to obtain the required dc output. Proper operation of these circuits is indicated by the presence of a smooth dc output voltage exhibiting the volt-ampere characteristics referenced above.

The screen, accelerator, and anode supplies are protected against overload by the instant-off circuit. Application of an overload to any of these supplies results in shutdown of the power amplifier for 0.01-1.0 second depending upon the setting of resistor R50. The neutralizer bias supply is a soft-source supply inherently current-limited by its characteristics. This supply, therefore, is capable of withstanding short circuits without shutting down.

AC Outputs. - The thrustor cathode, thrustor feed, neutralizer cathode, and neutralizer vaporizer supplies provide pulse-width-modulated ac outputs. The thrustor feed is a voltage regulated supply, while the remaining three supplies are current regulated. The volt-ampere characteristics of each of these outputs is presented in Figures 31 through 34.

Overloads on any of these supplies are sensed by the delayed-off circuit which shuts down the power conditioner after an overload exists for eight seconds. The short circuit current in the feed supply is limited by the winding resistance of the magnetic amplifier AR2 and the output transformer T6.

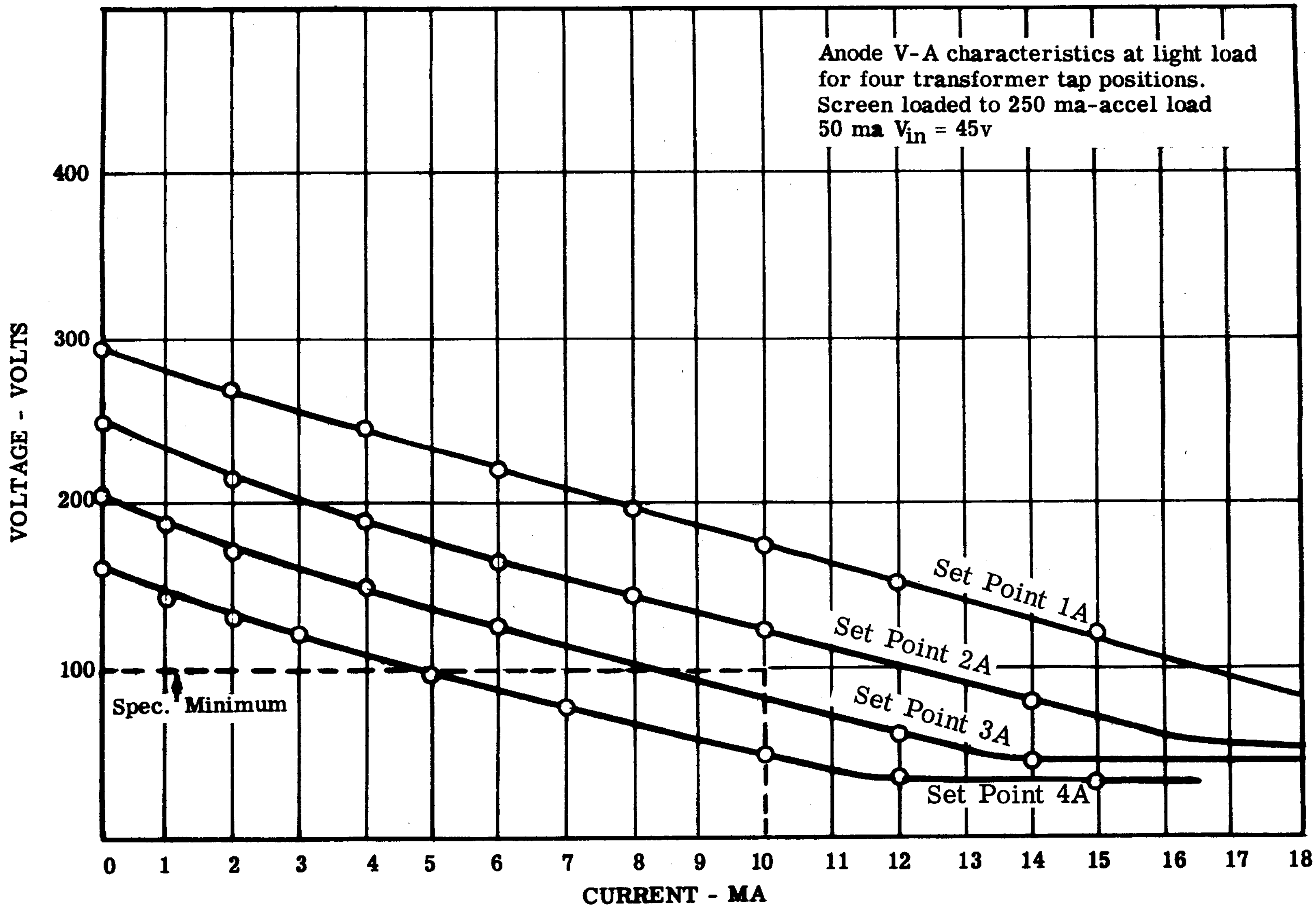


FIGURE 24. Anode (low current) Characteristics at V_{in} = 45V

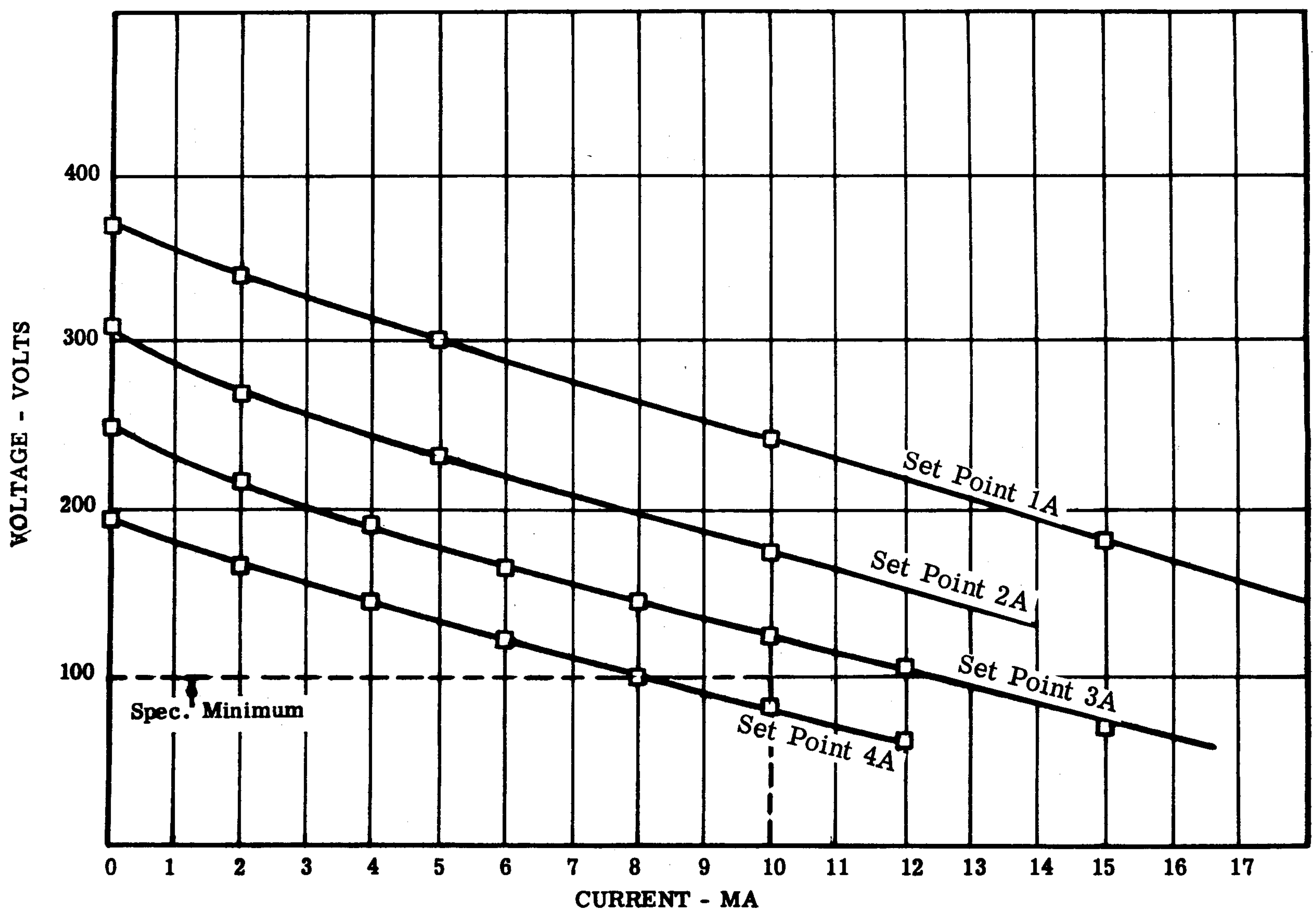


FIGURE 25. Anode (low current) Characteristics at V_{in} = 55V

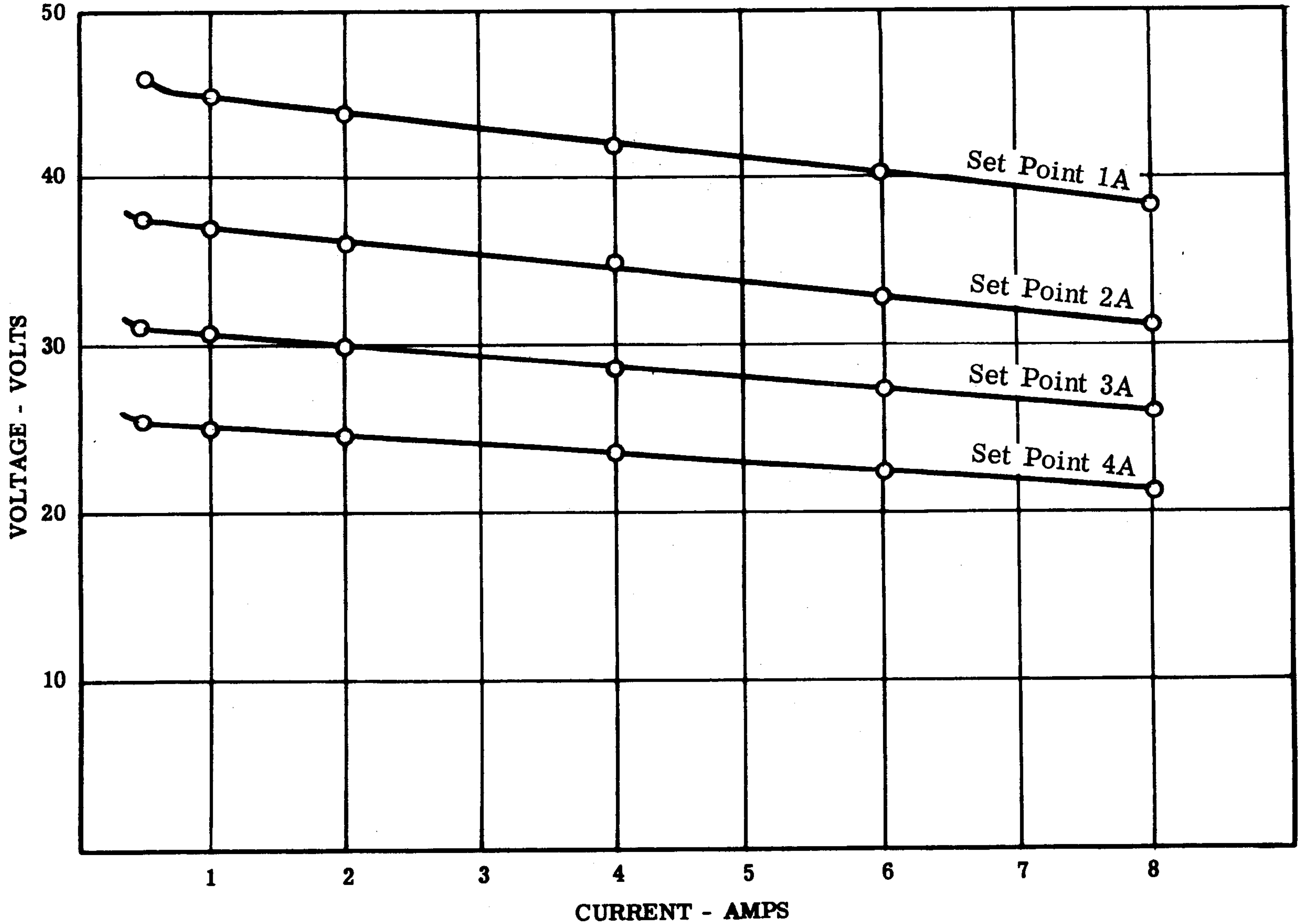


FIGURE 26. Anode (high current) Characteristics at V_{in} = 45V

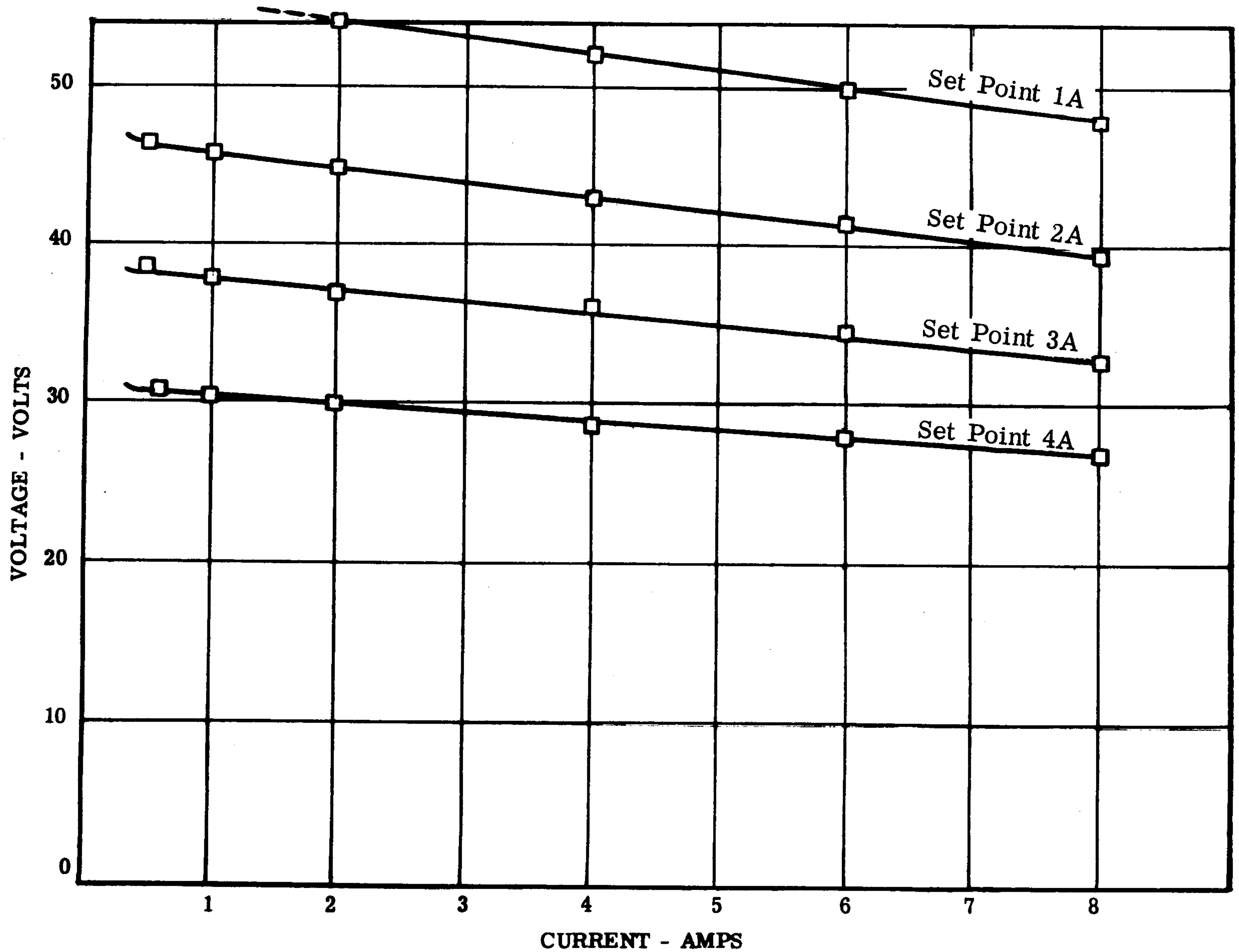


FIGURE 27. Anode (high current) Characteristics at V_{in} = 55V

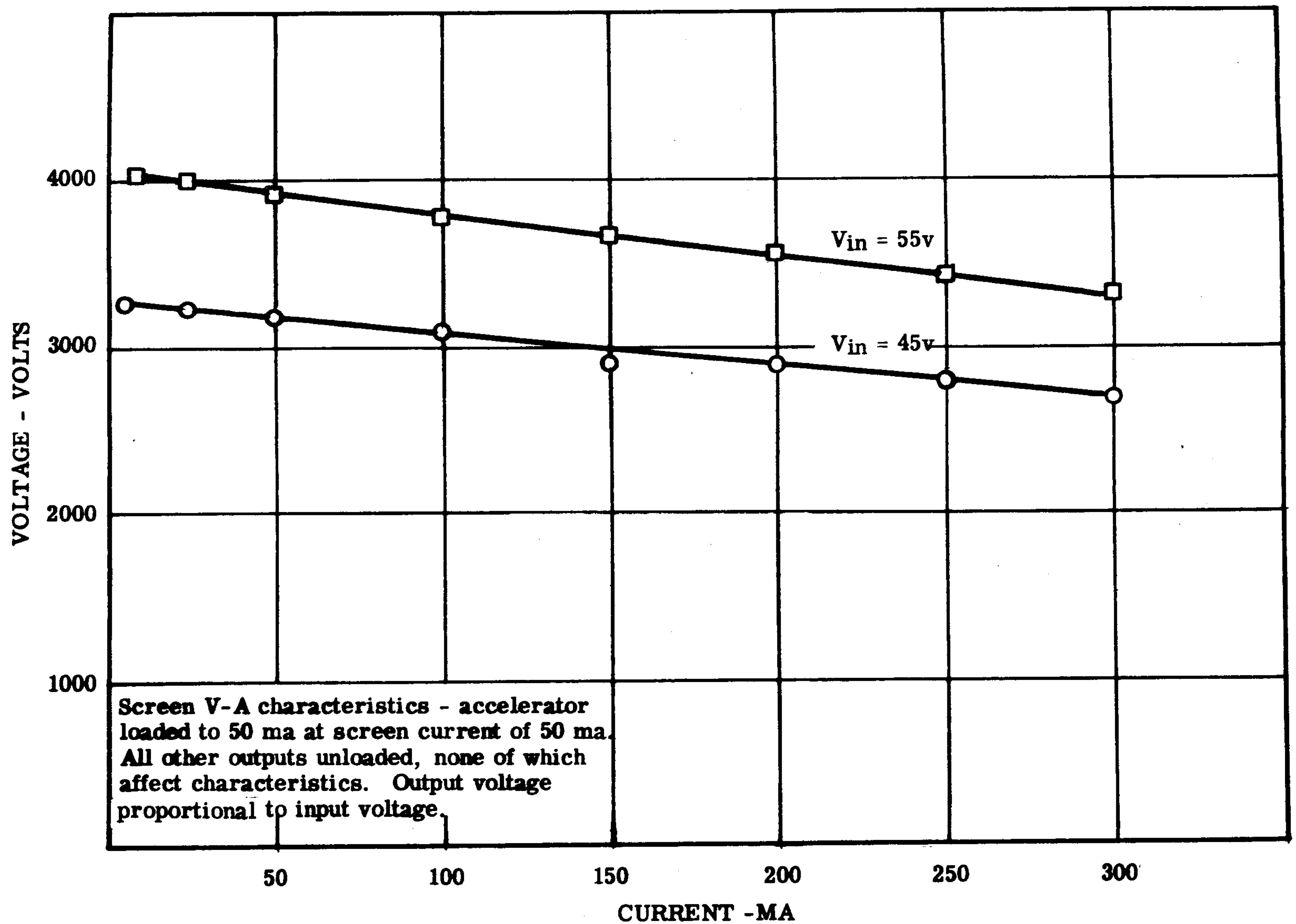


FIGURE 28. Screen Characteristics

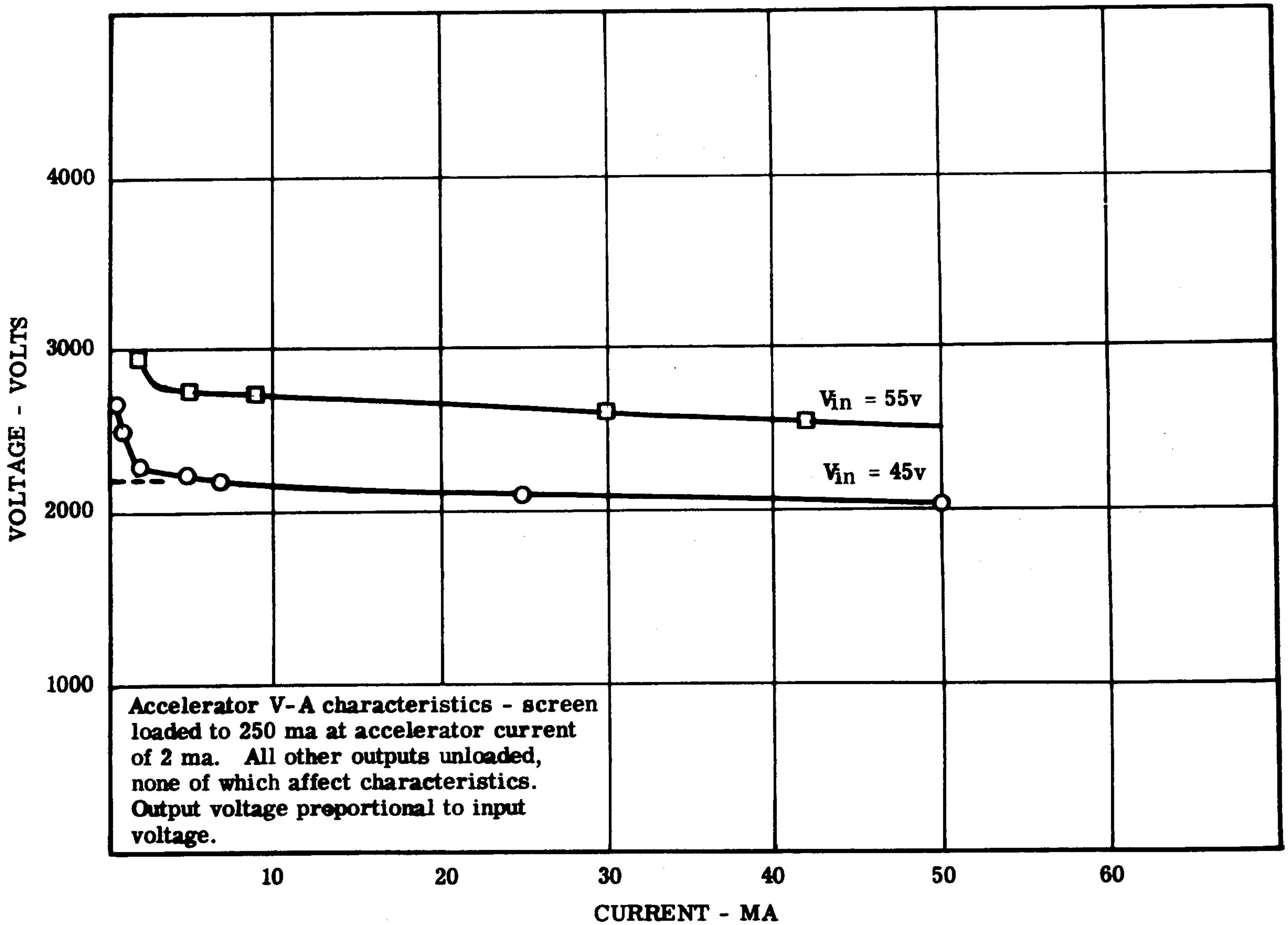


FIGURE 29. Accelerator Characteristics

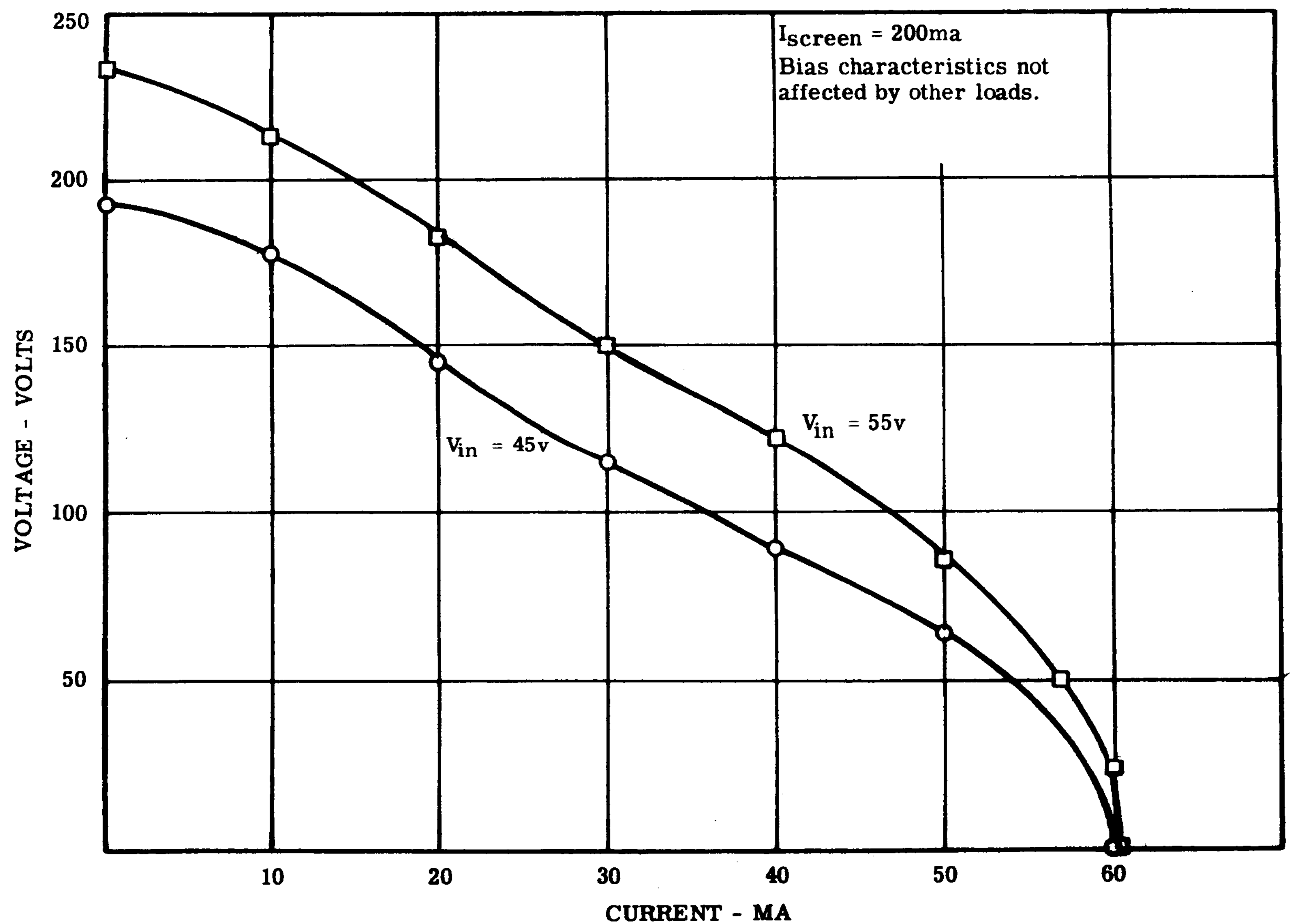


FIGURE 30. Neutralizer Bias Characteristics

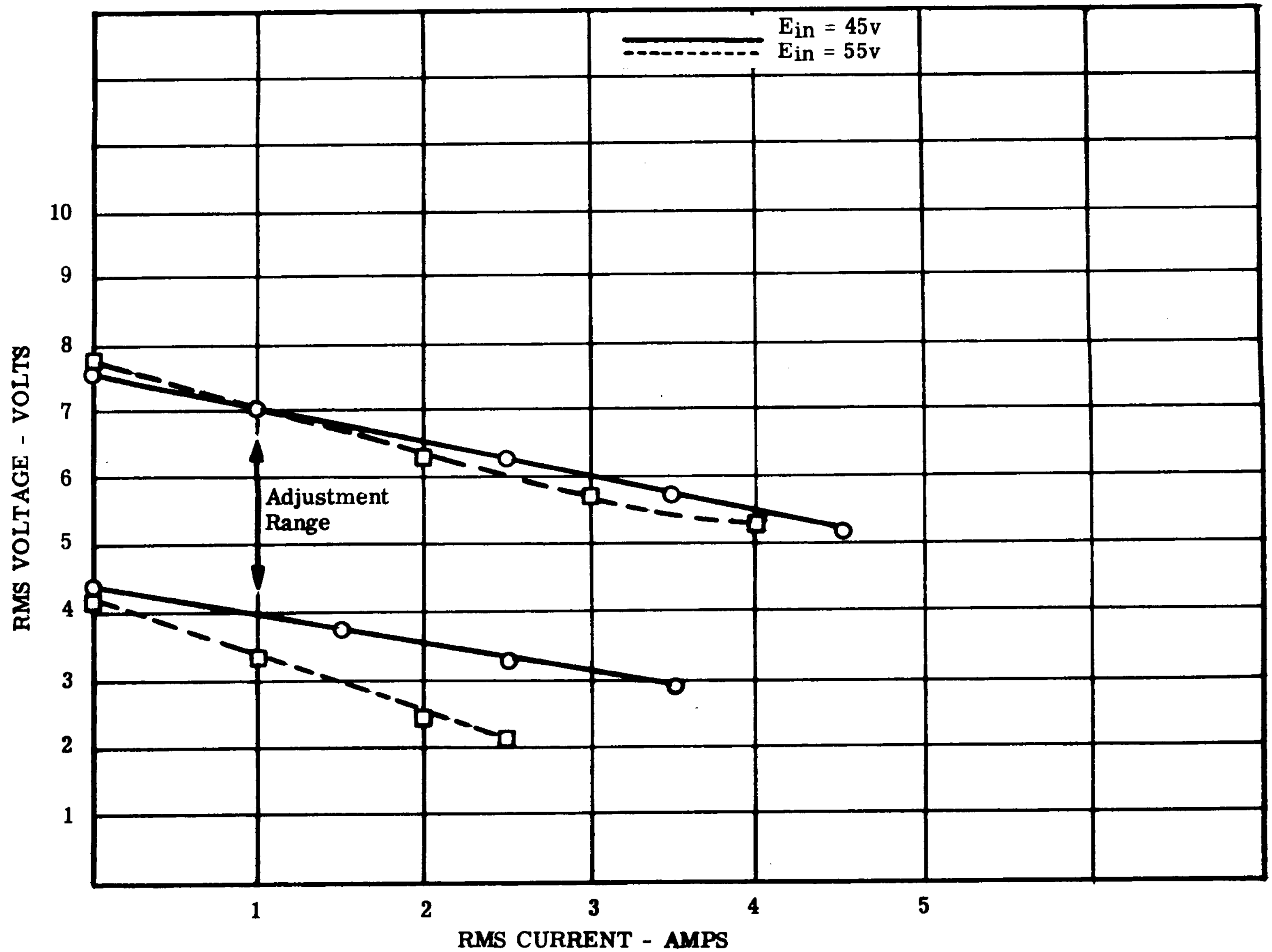


FIGURE 31. Feed Characteristics

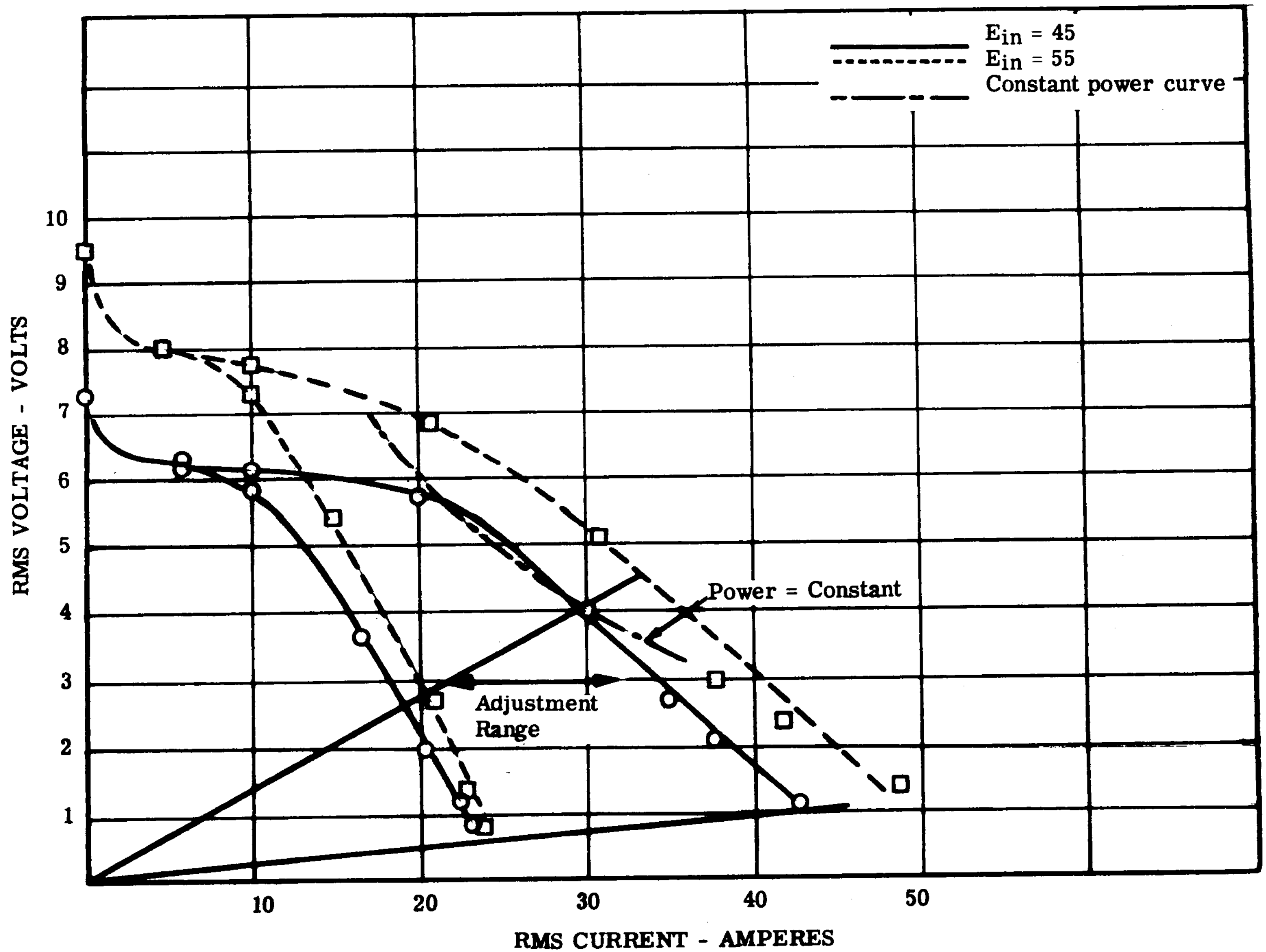


FIGURE 32. Cathode Characteristics

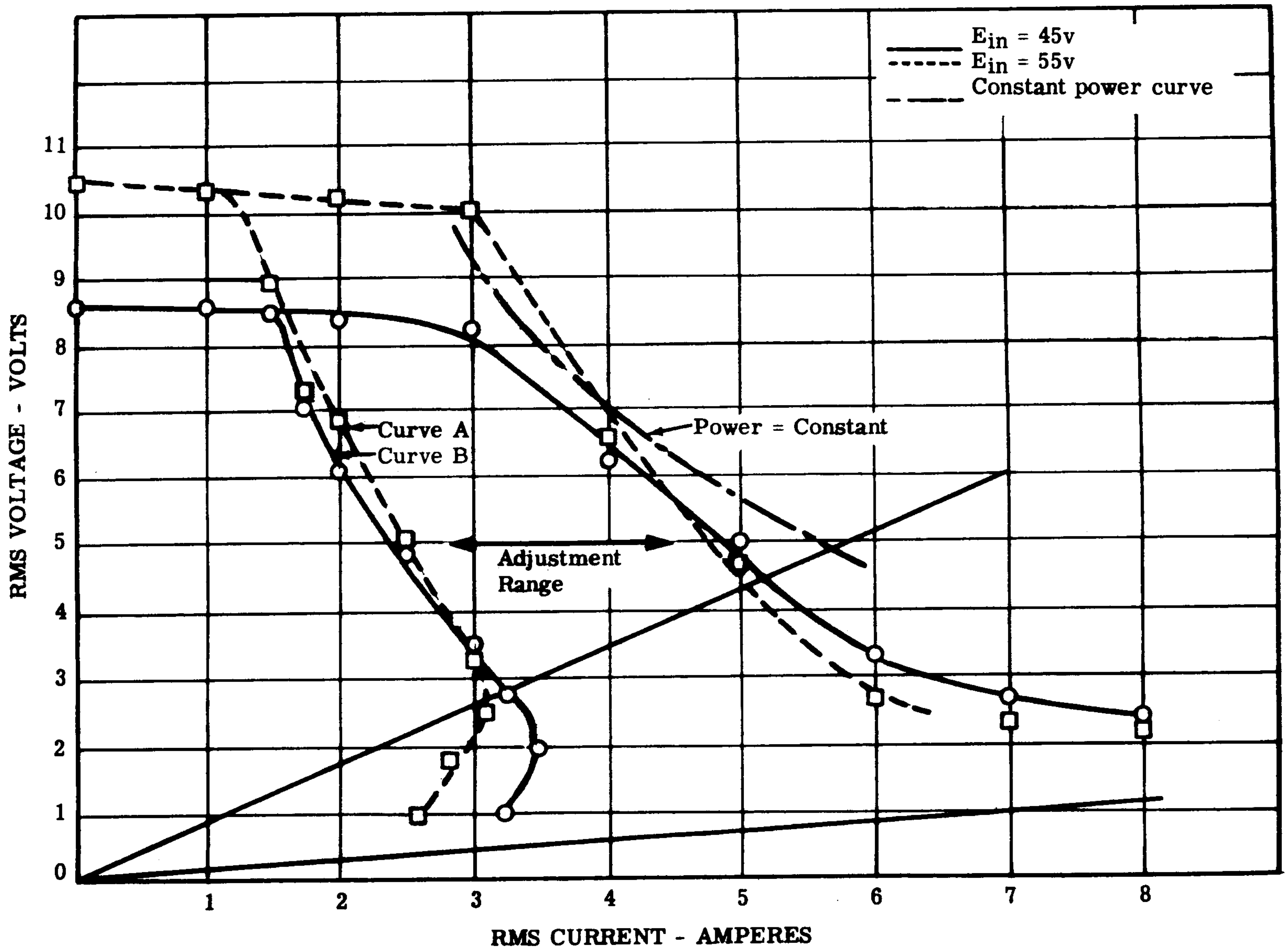


FIGURE 33. Neutralizer Cathode Characteristics

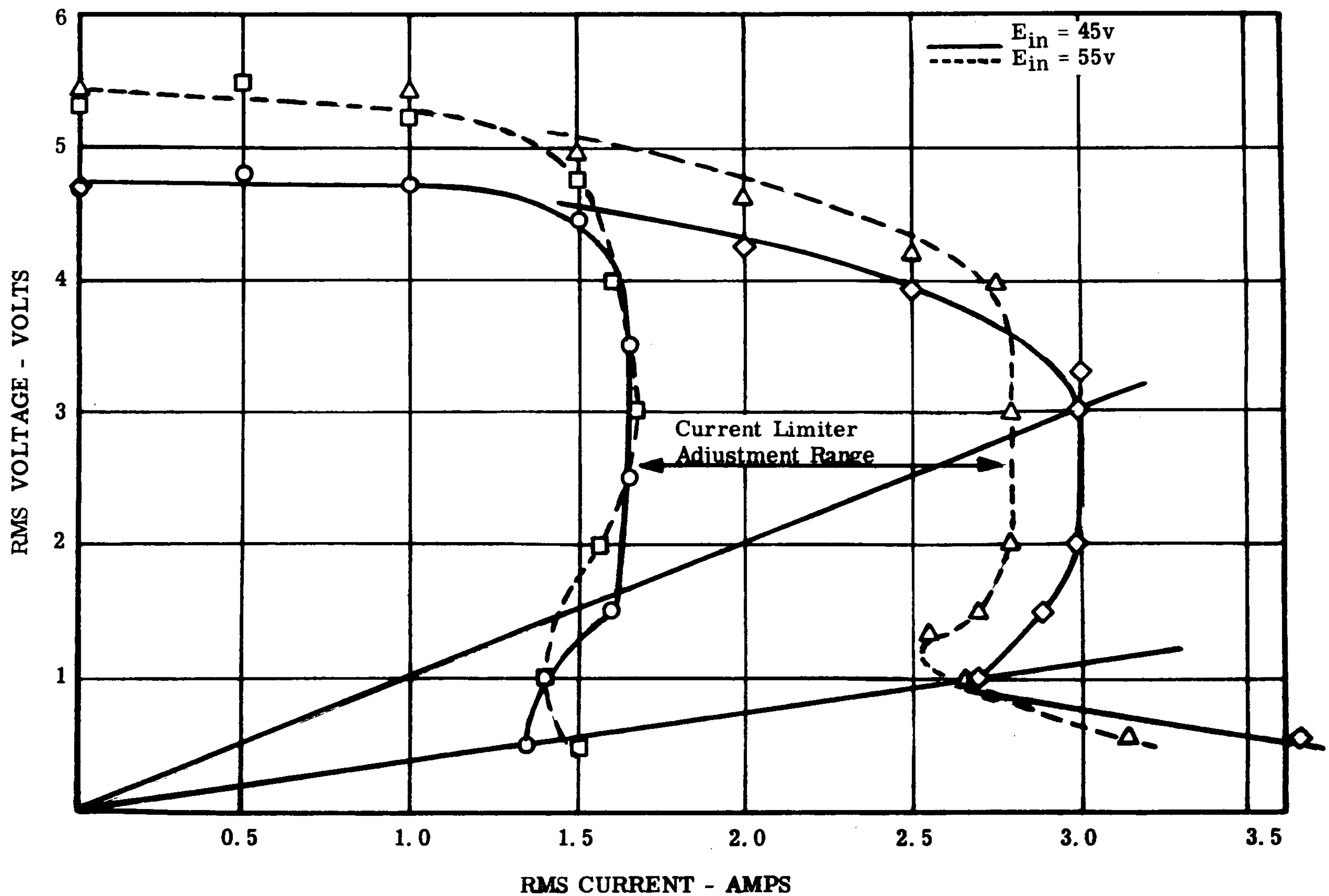


FIGURE 34. Neutralizer Vaporizer Characteristics

Since the remaining three supplies are current regulated, the rms current is limited by closed-loop regulator action, while the peak currents are again limited by the winding resistance of the magnetic devices.

While restart of the power conditioner is automatic after an instant-off condition, a shutdown by the delayed-off circuit requires a command signal to resume operation.

DC Sensing. - Sensing of dc currents and voltages is accomplished by one of three methods. Where possible, currents are sensed by insertion of a series resistance which provides a voltage drop proportional to the current. This method is used in the screen supply (R17) and the accelerator supply (R24, R25). Likewise, dc voltages are sensed by a voltage divider as in the screen supply (R15, R16), and in sensing of the input voltage (R40, R42; R113, R114; R109, R120).

Where isolation is required, the dc currents and voltages are sensed before the power rectifiers through isolation transformers, with the resulting output rectified and filtered. This method is utilized in the anode supply (T14, T15), the accelerator supply (winding 3 of T1), the neutralizer bias supply (T23), and the power amplifier (T17).

Input current to the power conditioner is sensed by magnetic amplifier AR1. The resulting pulse-width-modulated signal is rectified and filtered to provide the required dc voltage.

RMS Sensing. - Control of the pulse width of the ac supplies requires a dc current in the control winding of the magnetic amplifiers. This control current is directly proportional to the value by which the actual load current exceeds the desired load current. To obtain a signal of this type, an rms/dc converter is utilized in the sensing circuits. For example, load current in the neutralizer vaporizer circuit is sensed by transformer T21 and rectified by a full-wave bridge. The resulting waveshape is amplified by transistor Q22, and changed to a smooth dc voltage by the rms/dc converter consisting of C27, R90, R104, and C7. The output of the rms/dc converter is amplified by Q7 and applied to resistor R58. When the voltage at the top of R58 becomes greater than the breakdown voltage of diode CR31, a current flows into the control winding of AR5. This phases back the output of AR5, thereby maintaining the load current at the desired level.

Sensing of all of the ac currents and voltages is accomplished in a similar manner.

Overload Protection. - Protection against overloads is provided by the instant-off and the delayed-off circuit. The instant-off circuit senses load current in the anode supply as well as the instantaneous collector current in the main power transistors Q1 and Q2. The presence of an overload signal trips the instant-off circuit, and provides base drive to transistor Q18. This in turn shorts out a winding on transformer T2 which removes all base drive from Q1 and Q2. The duration of the off time is adjustable by means of potentiometer R50 between 0.01 and 1.0 seconds.

The delayed-off circuit senses load currents in the cathode, feed, neutralizer cathode, and neutralizer vaporizer supplies. If an overload signal exists for longer than eight seconds, transistor Q26 is turned on. This energizes latching relay K4 which shuts down the power conditioner. The condition of the instant-off circuit is also sensed by the delayed-off circuit, and provides automatic shutdown of the unit in the event that the instant-off condition repeats itself rapidly.

Telemetry Outputs. - All of the sensing circuits described previously produce dc signal voltages proportional to the measured variable. All telemetry outputs are obtained by means of voltage dividers from these voltages. The voltage dividers perform a threefold function. They provide telemetry signals of the proper magnitude; they provide a soft-source for the voltage limiting diode; they provide isolation so that short circuits on the telemetry terminals will not affect power conditioner operation. The telemetry calibration curves for the various measured parameters are presented in Figures 35 through 50.

In addition to providing a voltage limiting function, the avalanche diodes provide protection against arcing from both positive and negative supplies.

Command Control. - The remote control panel provided with the power conditioner provides on-off control of the power conditioner as well as control of the various command functions. Identification of the control panel switch positions is shown on the schematic diagram.

Potentiometer Adjustments. - Numerous potentiometers are provided throughout the power conditioner to control the performance characteristics. The location of each of these potentiometers can be determined by means of Figure 1 and Figures 6 through 19 in conjunction with the schematic diagram.

Miscellaneous Provisions. - A 50-ampere circuit breaker is provided on the front panel of the power conditioner. This breaker provides a protective function should a component fault occur, and also allows a convenient

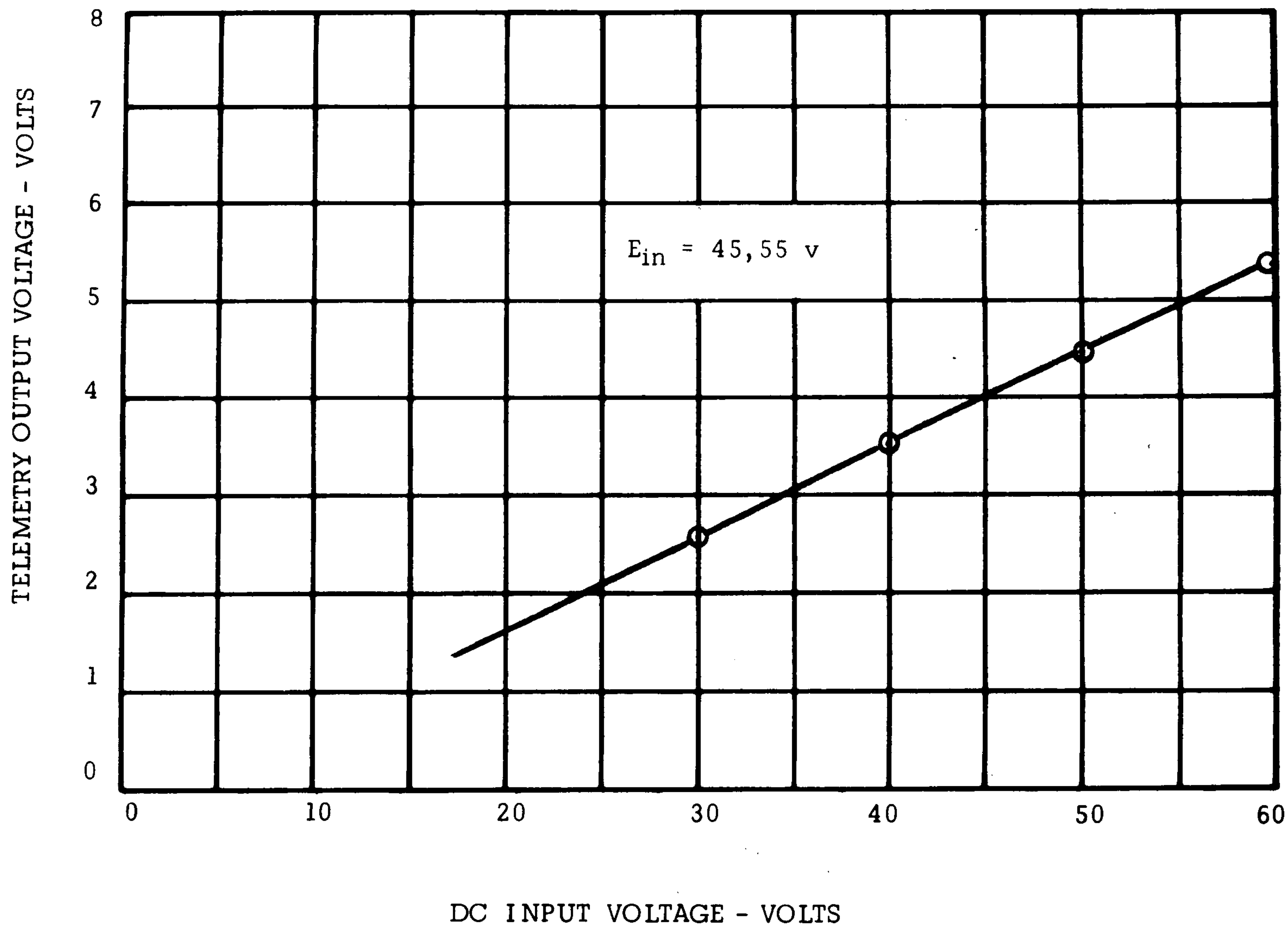


FIGURE 35. POWER CONDITIONER INPUT VOLTAGE TELEMETRY CALIBRATION

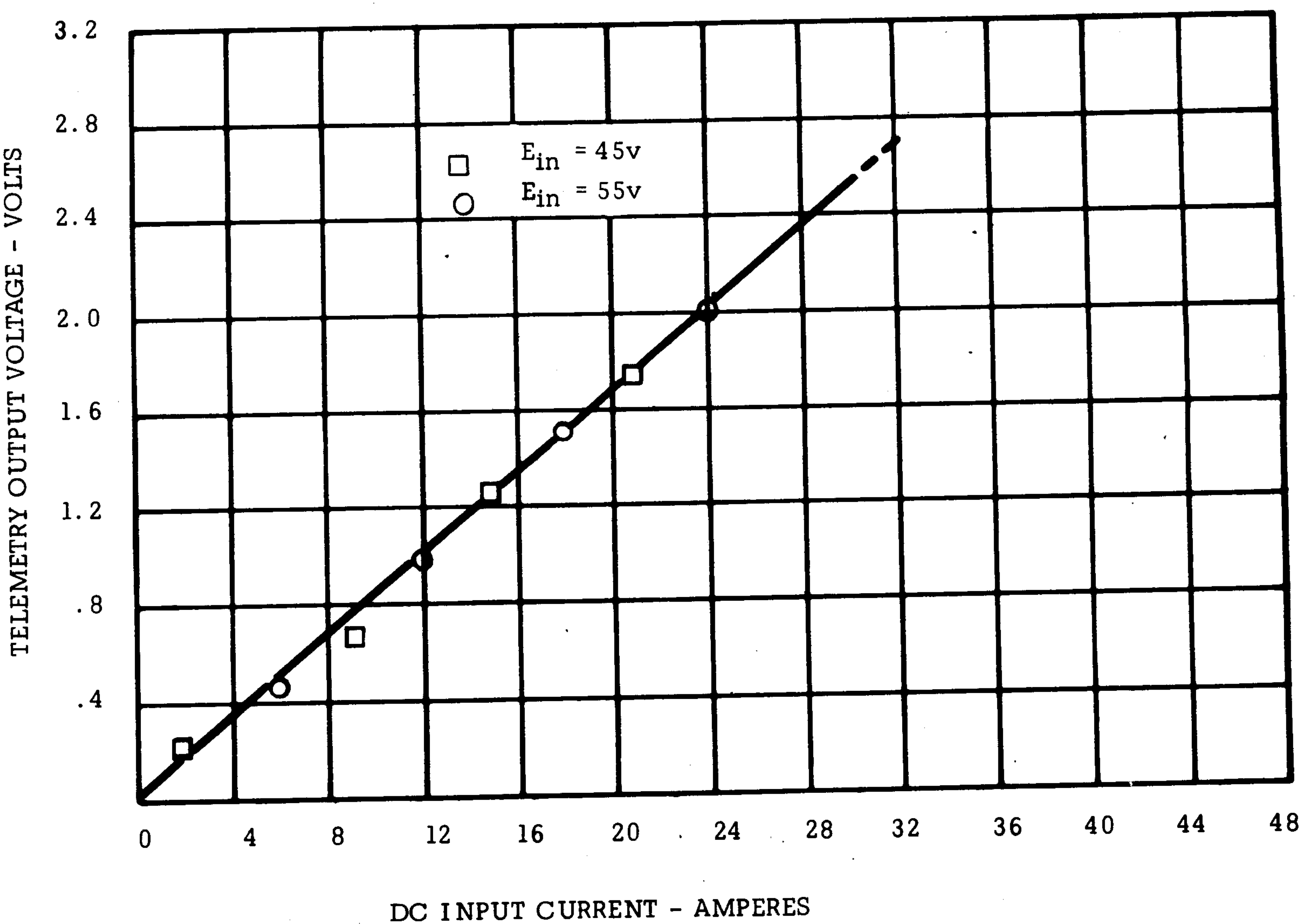


FIGURE 36. POWER CONDITIONER INPUT CURRENT TELEMETRY CALIBRATION

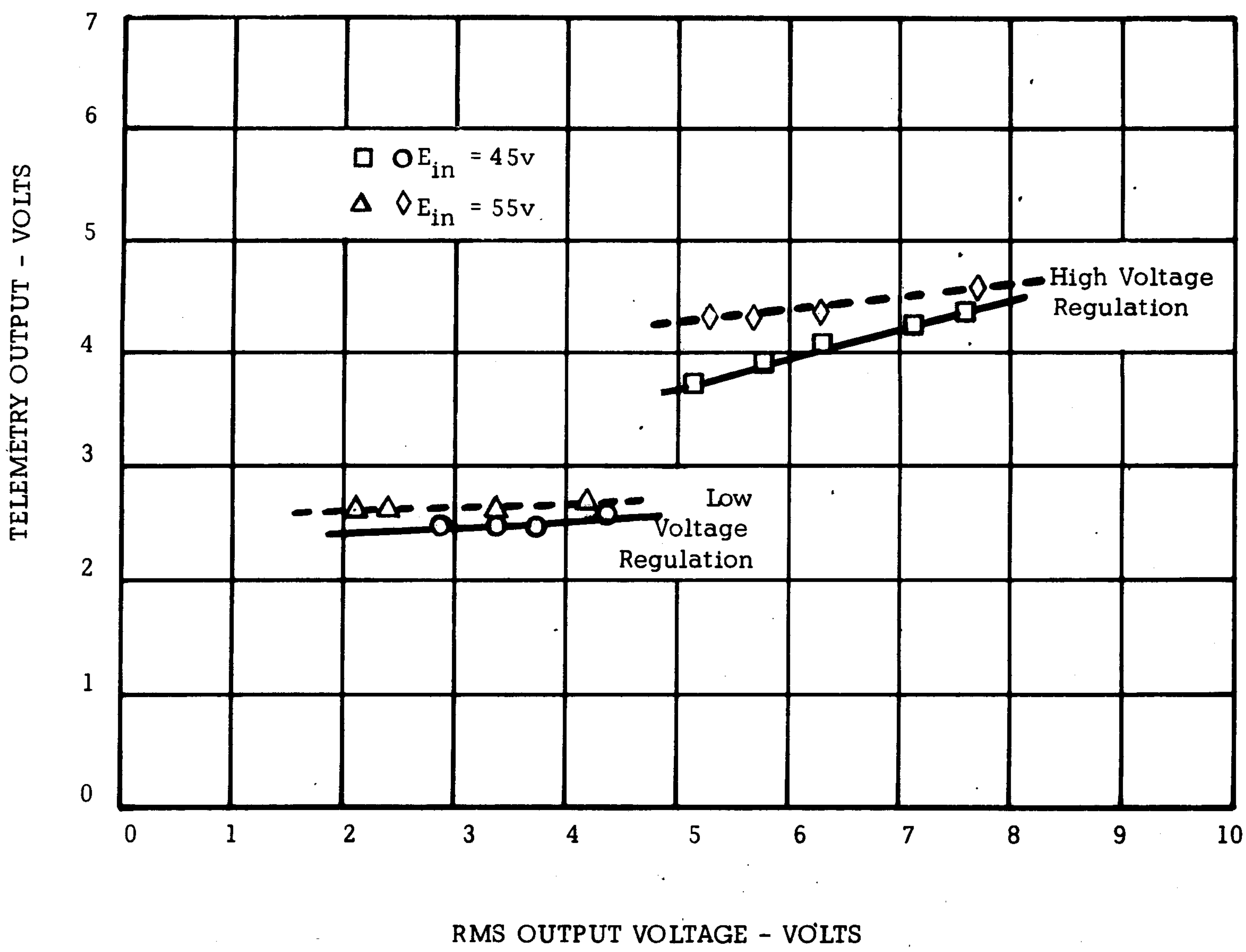


FIGURE 37. FEED VOLTAGE TELEMETRY CALIBRATION

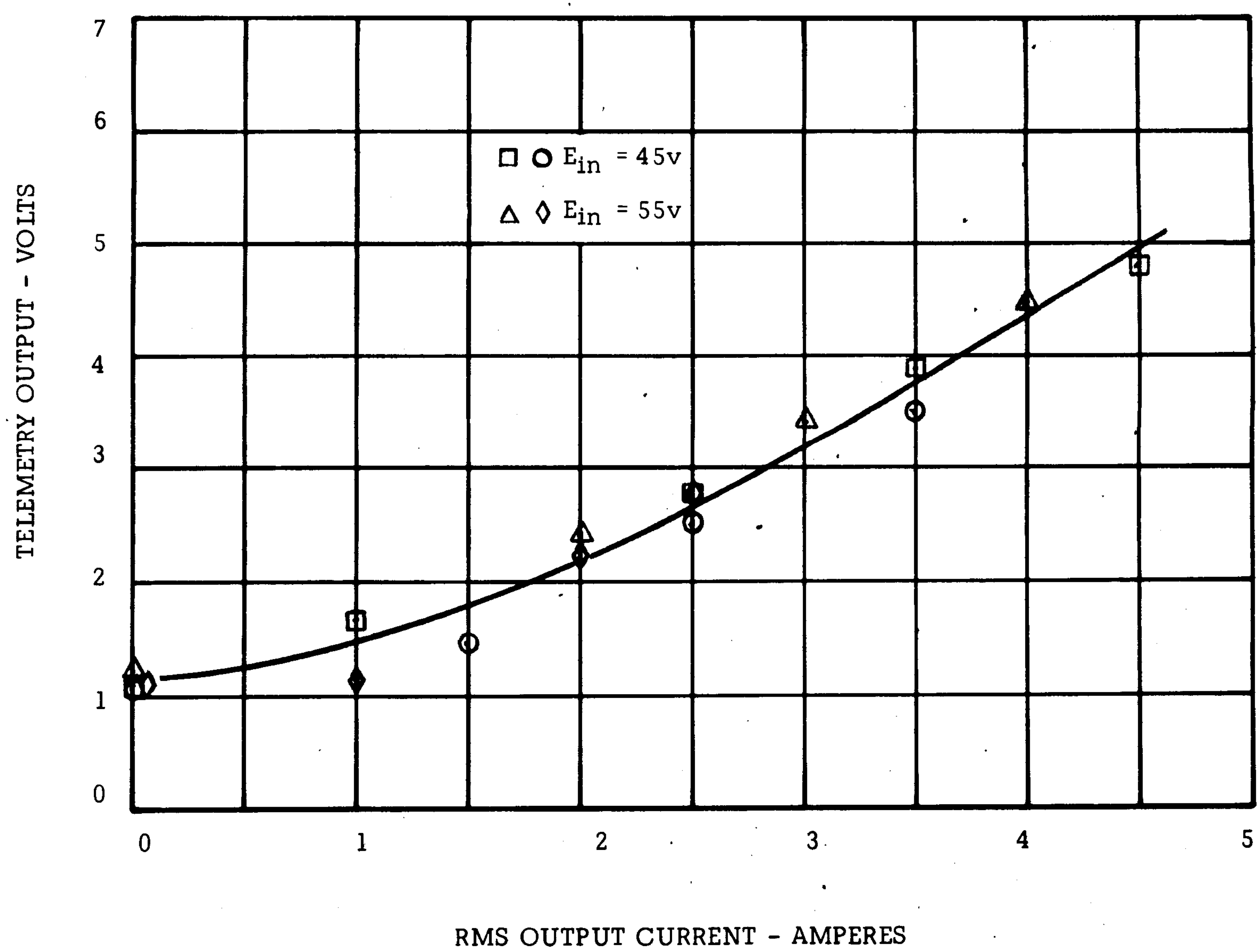


FIGURE 38. FEED CURRENT TELEMETRY CALIBRATION

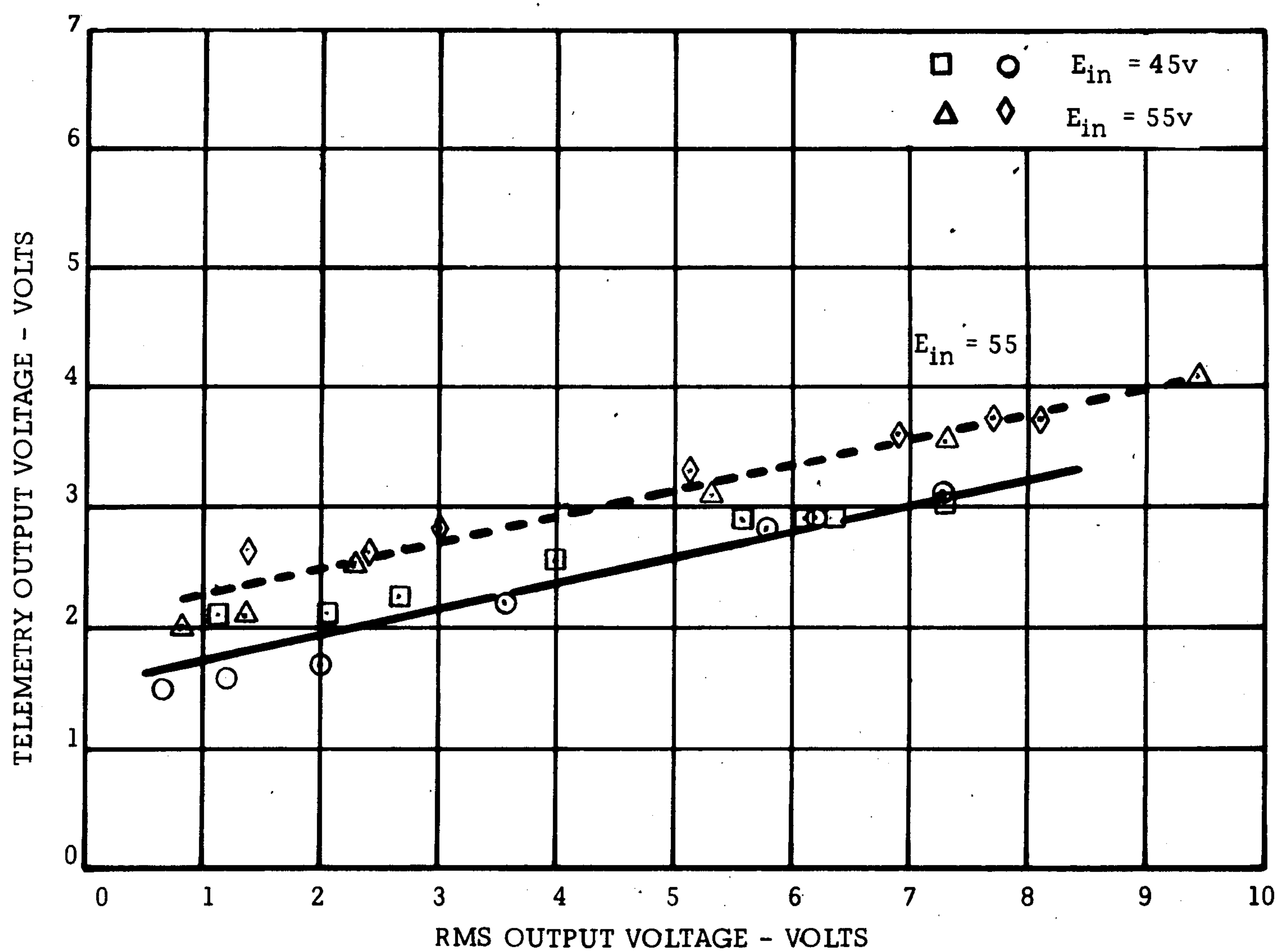


FIGURE 39. CATHODE VOLTAGE TELEMETRY CALIBRATION

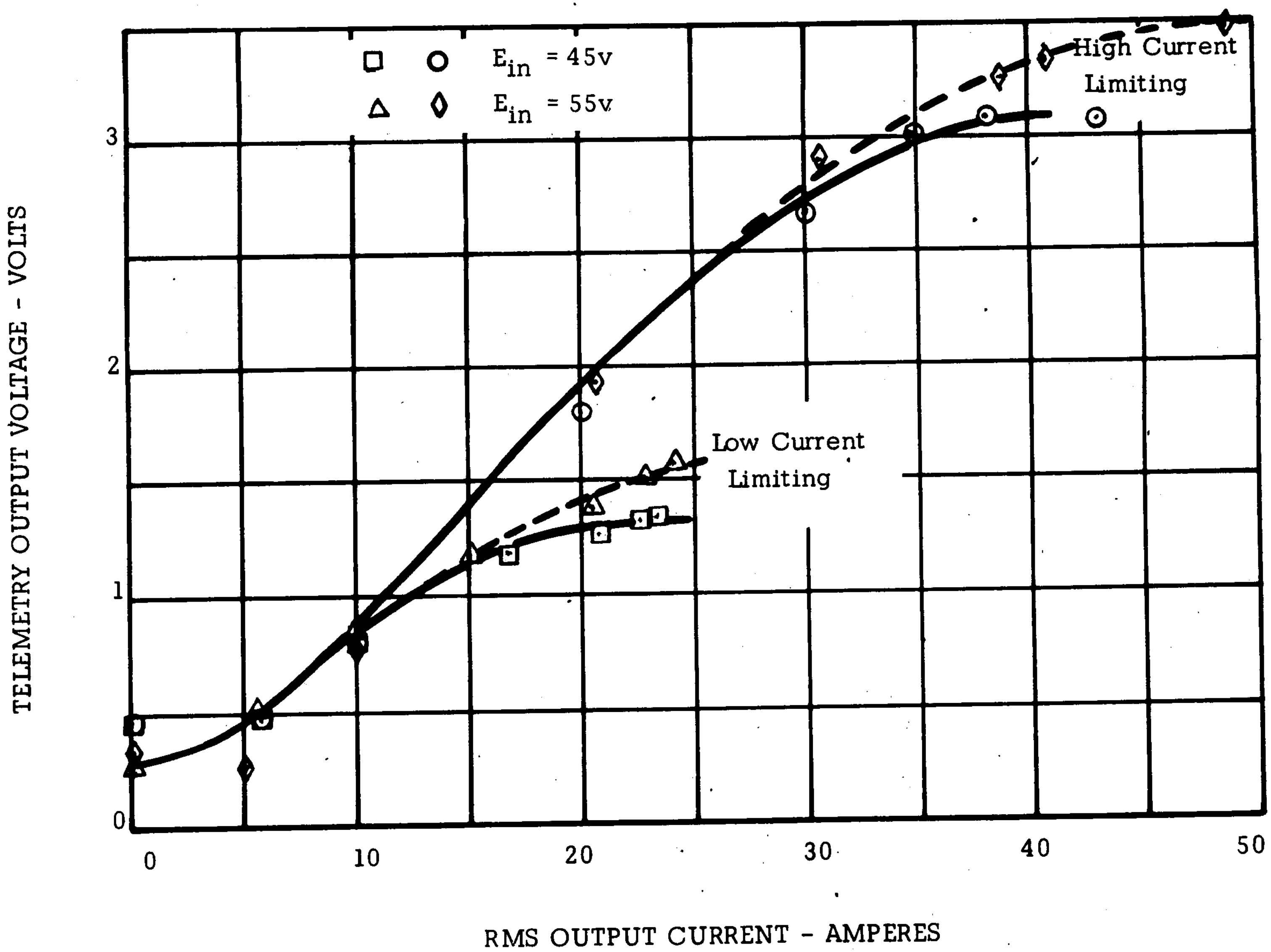


FIGURE 40. CATHODE CURRENT TELEMETRY CALIBRATION

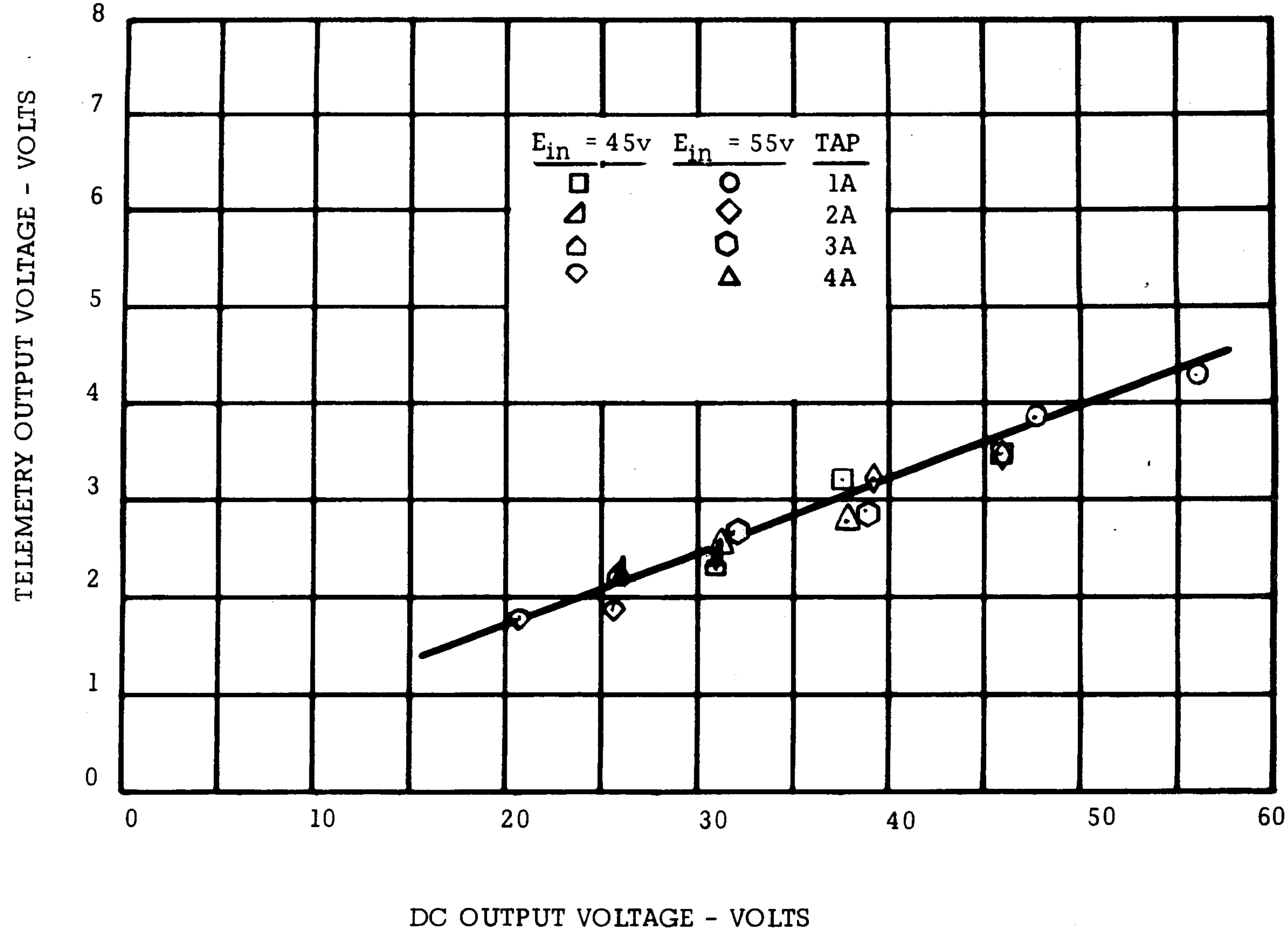


FIGURE 41. ANODE VOLTAGE TELEMETRY CALIBRATION

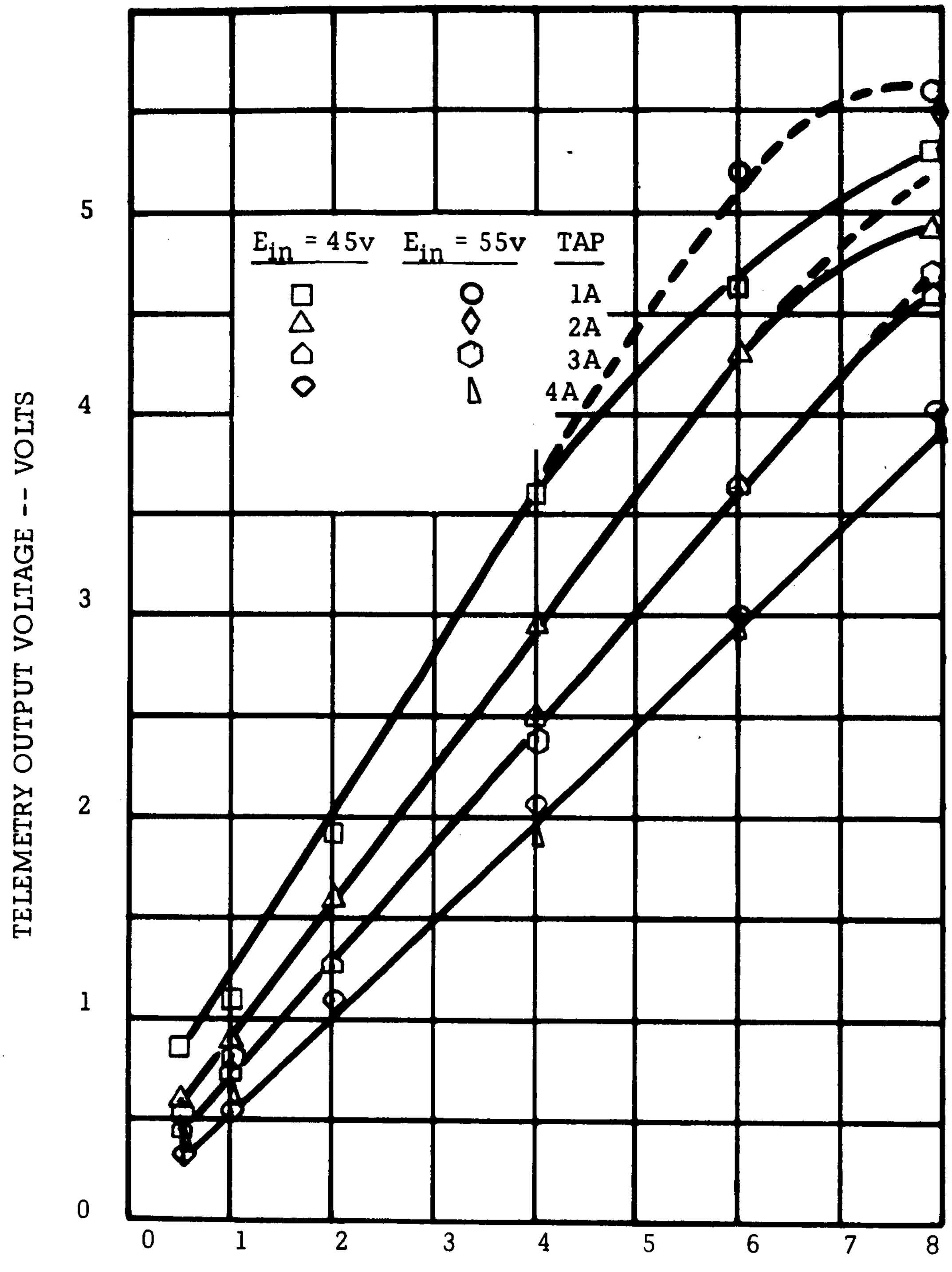


FIGURE 42. ANODE CURRENT TELEMETRY CALIBRATION

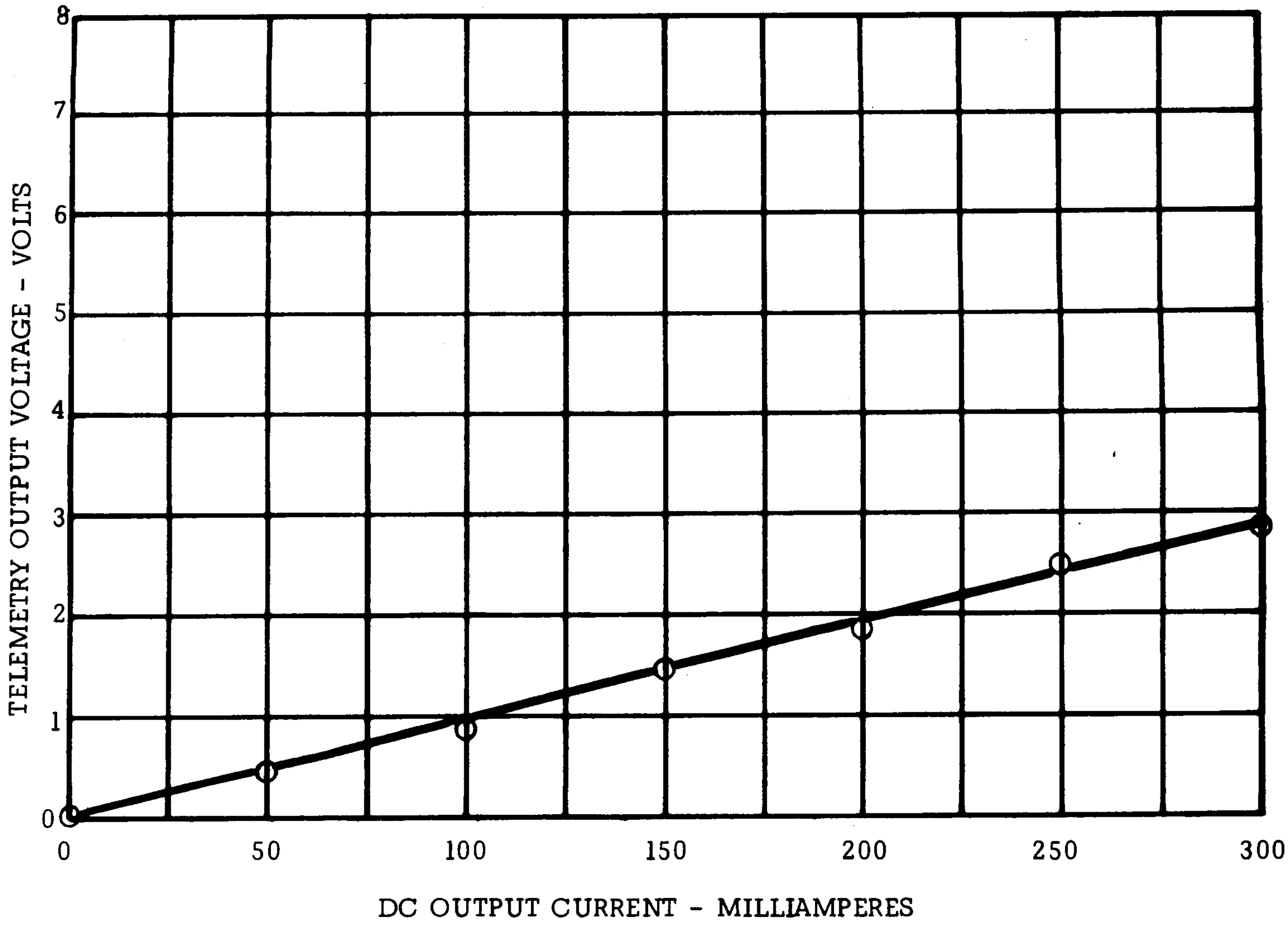


FIGURE 43. SCREEN CURRENT TELEMETRY CALIBRATION

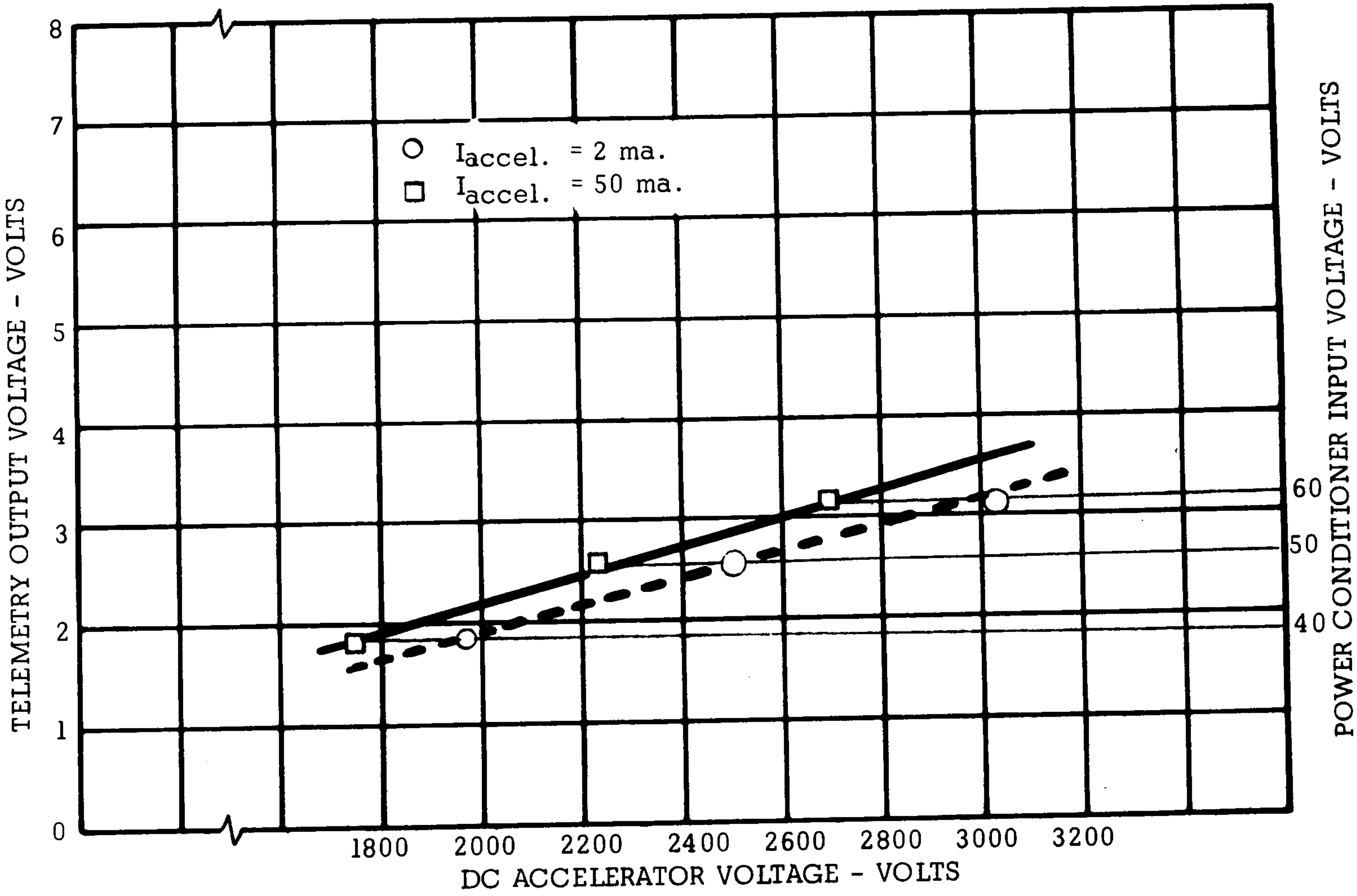


FIGURE 44. ACCELERATOR VOLTAGE TELEMETRY CALIBRATION

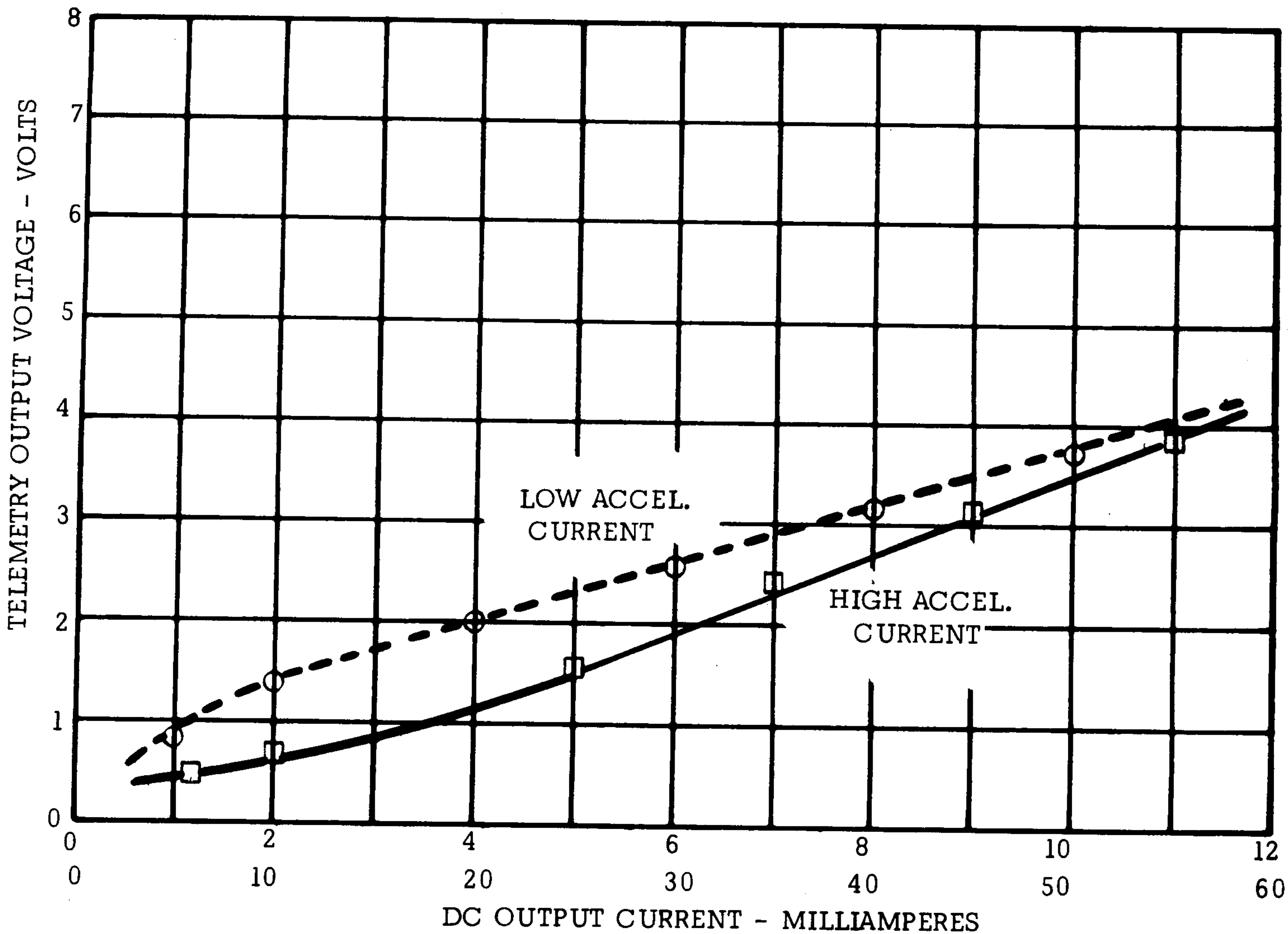


FIGURE 45. ACCELERATOR CURRENT TELEMETRY CALIBRATION

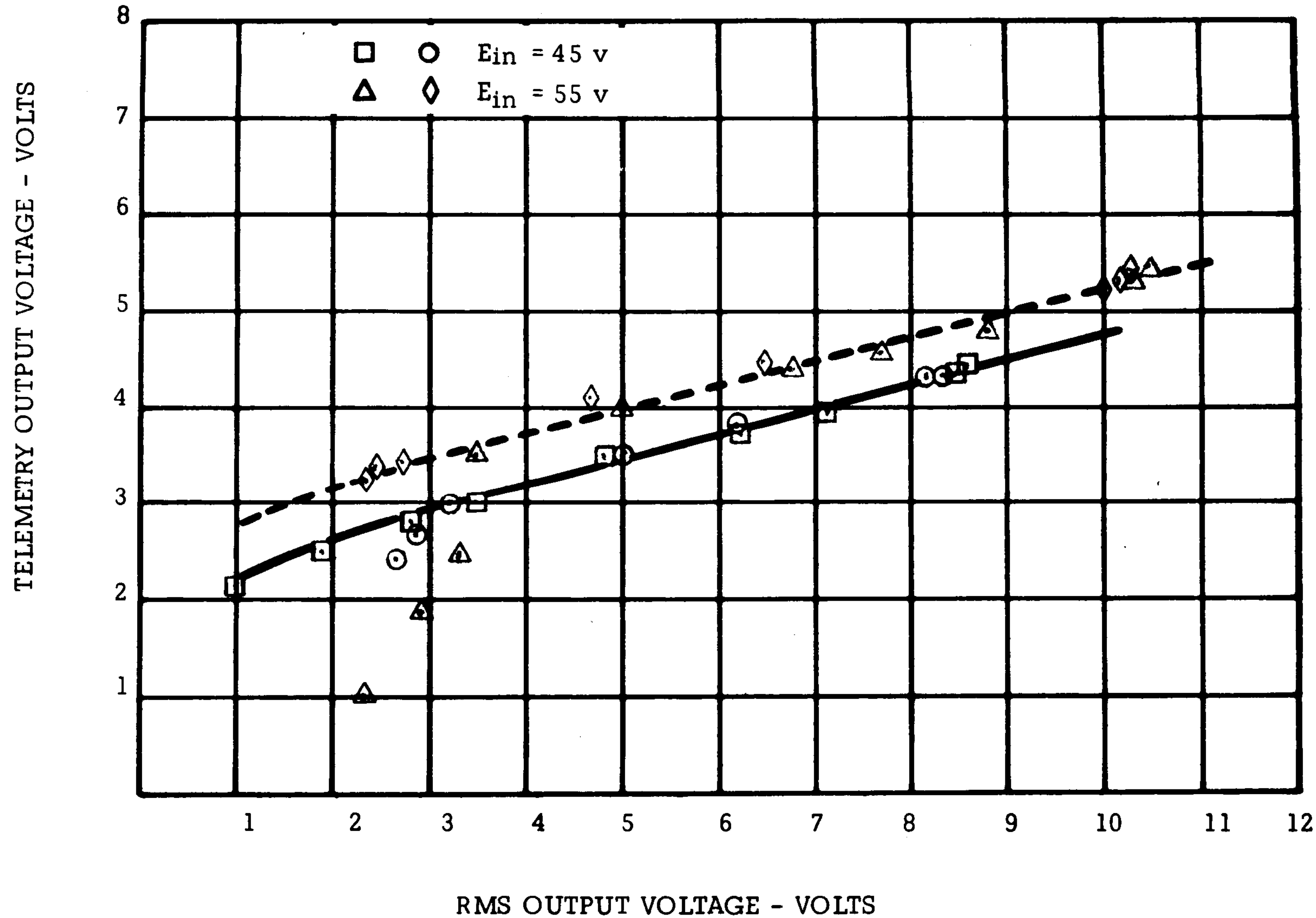


FIGURE 46. NEUTRALIZER CATHODE VOLTAGE TELEMETRY CALIBRATION

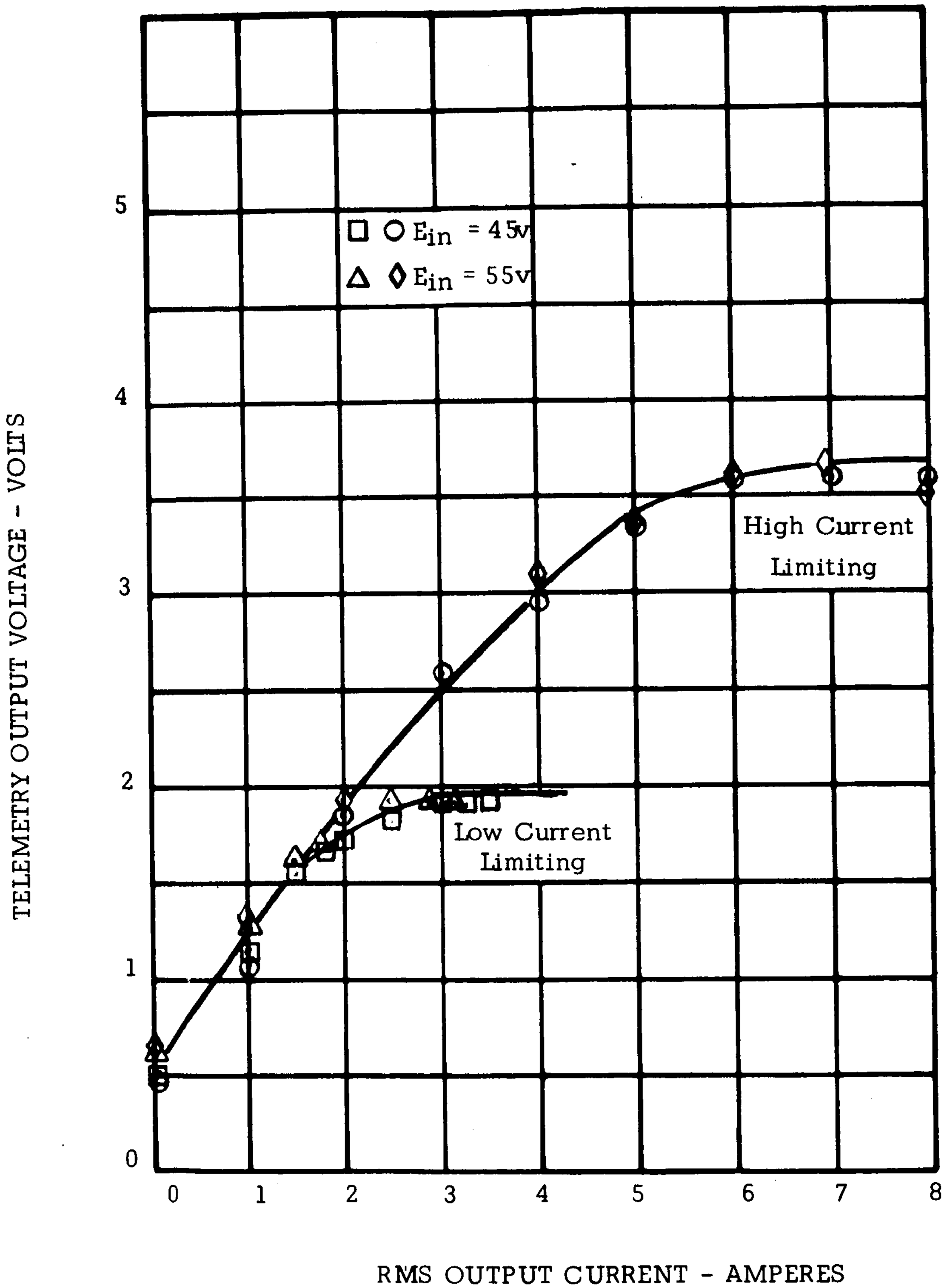


FIGURE 47. NEUT. CATHODE CURRENT TELEMETRY CALIBRATION

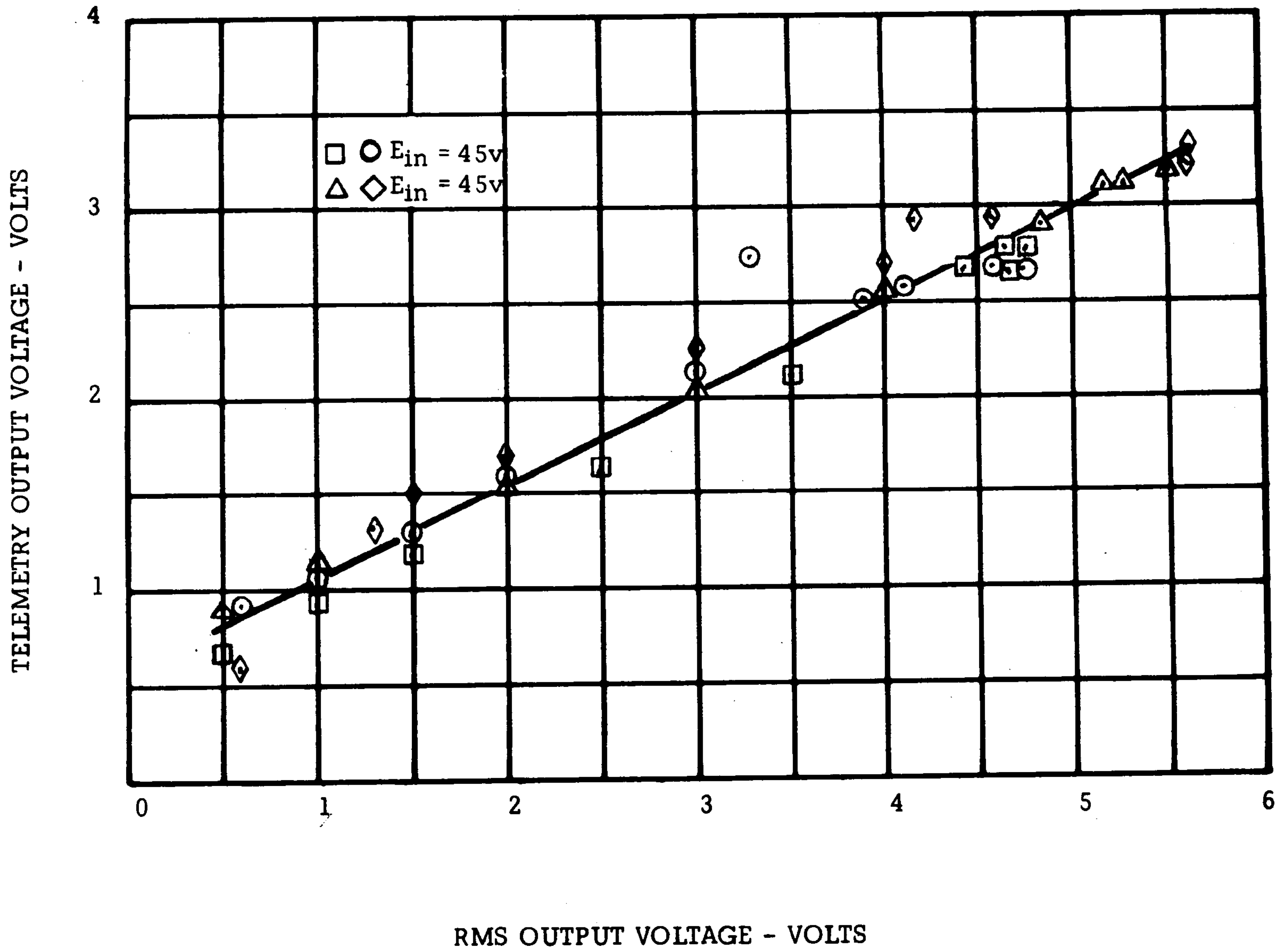


FIGURE 48. NEUT. VAPORIZER VOLTAGE TELEMETRY CALIBRATION

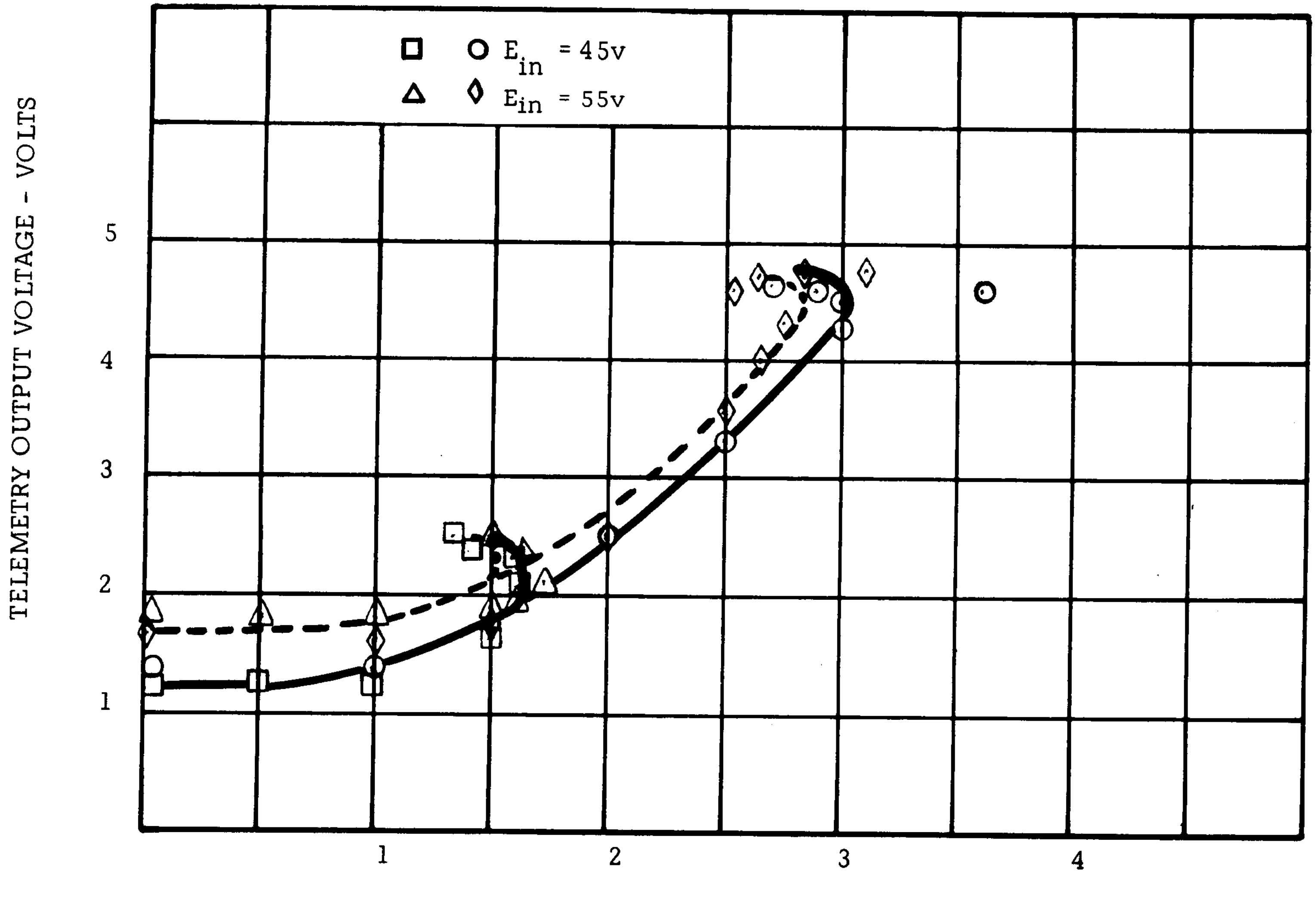


FIGURE 49. NEUT. VAPORIZER CURRENT TELEMETRY CALIBRATION

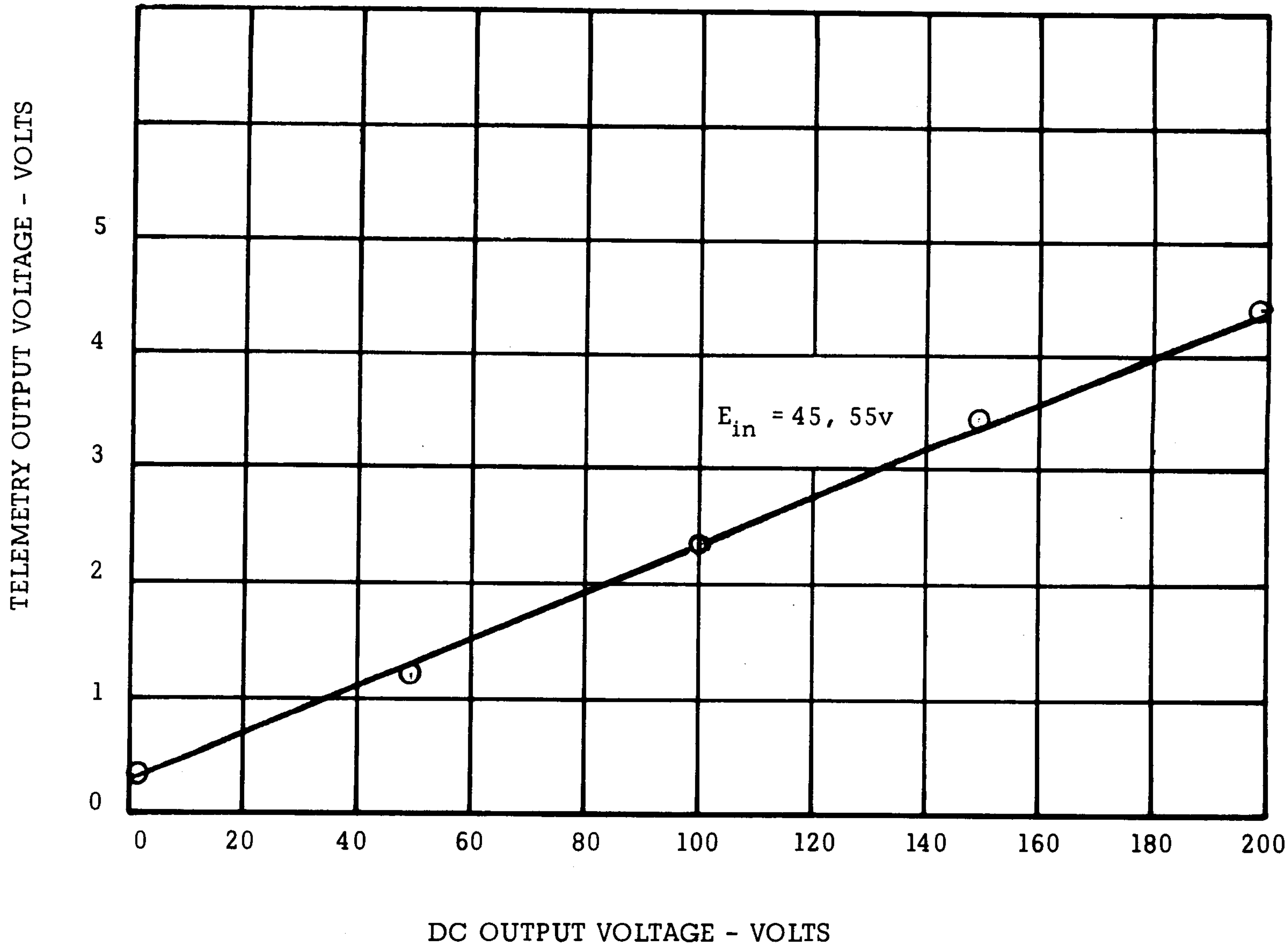


FIGURE 50. NEUT. BIAS VOLTAGE TELEMETRY CALIBRATION

means to de-energize the power conditioner.

Provisions have been made for three temperature sensing thermistors. One thermistor has been mounted in transformer T1, and another in the heatsink associated with transistor Q2. The third thermistor has not been included, and may be installed as needed.

A thermostat is mounted on the heatsink of transistor Q2. Designated S1 on the schematic, the thermostat provides an off signal to the power conditioner when the heatsink temperature reaches 100° C. The thermostat is incorporated to protect the main power transistors in case of blower failure. Should this situation occur, the power conditioner can be restarted as soon as the heatsink temperature drops below 100° C.

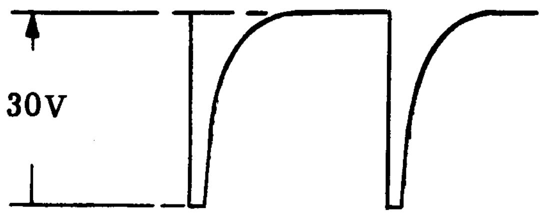
Detailed Circuit Analysis

The detailed circuit analysis presented herein refers to the schematic diagram, Figure 20, unless otherwise indicated. The operating waveshapes corresponding to the sets of two test points on the schematic are shown in Figure 51, while a detailed parts list is presented in the Appendix.

Squarewave Oscillator. - The squarewave oscillator shown in Figure 52 consists of transistors Q16 and Q17, transformer T19, and various associated components. The configuration is basically a Jensen oscillator, which utilizes a square-loop core material in the construction of T19 to determine the nominal 2-kHz switching frequency. The oscillator is turned off for extended periods by simultaneously removing the 40 to 60 volt input and by shorting one section of transformer T19. This action is accomplished by relay K4. The oscillator is turned off during over-voltage conditions by turning on transistor Q15 which shorts one section of T19, and removes the starting bias current provided through R128.

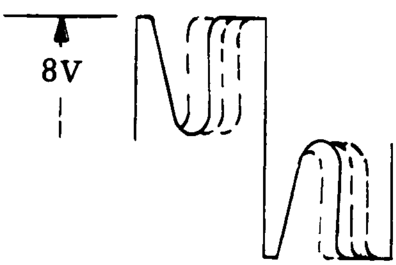
Circuit operation is described as follows: Assume Q16 to be off and Q17 to be on. Under these conditions a current flows from the 40 to 60 volt supply through K4 and R130 into the center tap of the primary of T19, then through CR56 and transistor Q17. The resulting voltage applied to T19 causes a positive voltage to appear at the base of Q17 causing a base current through this transistor limited only by R129. This base drive causes Q17 to remain on. When T19 saturates, base drive to Q17 is no

Numerals in left-hand column refer to test points, Figure 20
All values given are under nominal input voltage conditions of 45 volts

1 

f = 4 kHz

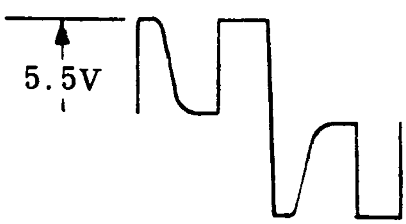
Inverter drive input voltage

2 

f = 2 kHz

Dotted waveshapes indicate possible pulse widths with load variation

Pulse-width-modulated output voltage - Feed Supply

3 

f = 2 kHz

Pulse-width-modulated output voltage - Cathode Supply

4 DC output - see volt-ampere characteristics

5 DC output - see volt-ampere characteristics

6 DC output - see volt-ampere characteristics

FIGURE 51. Operating Waveshapes

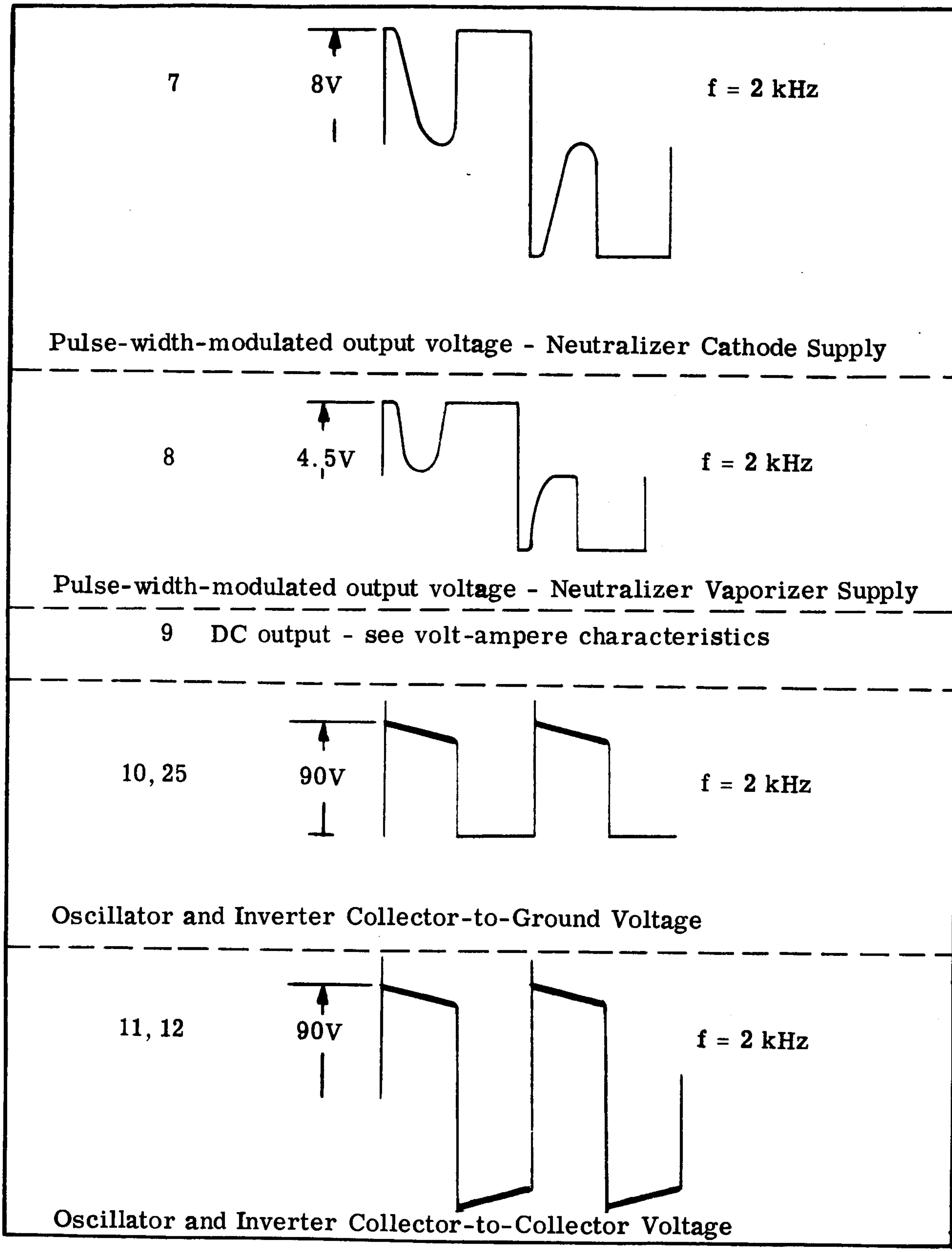


FIGURE 51. Operating Waveshapes - Continued

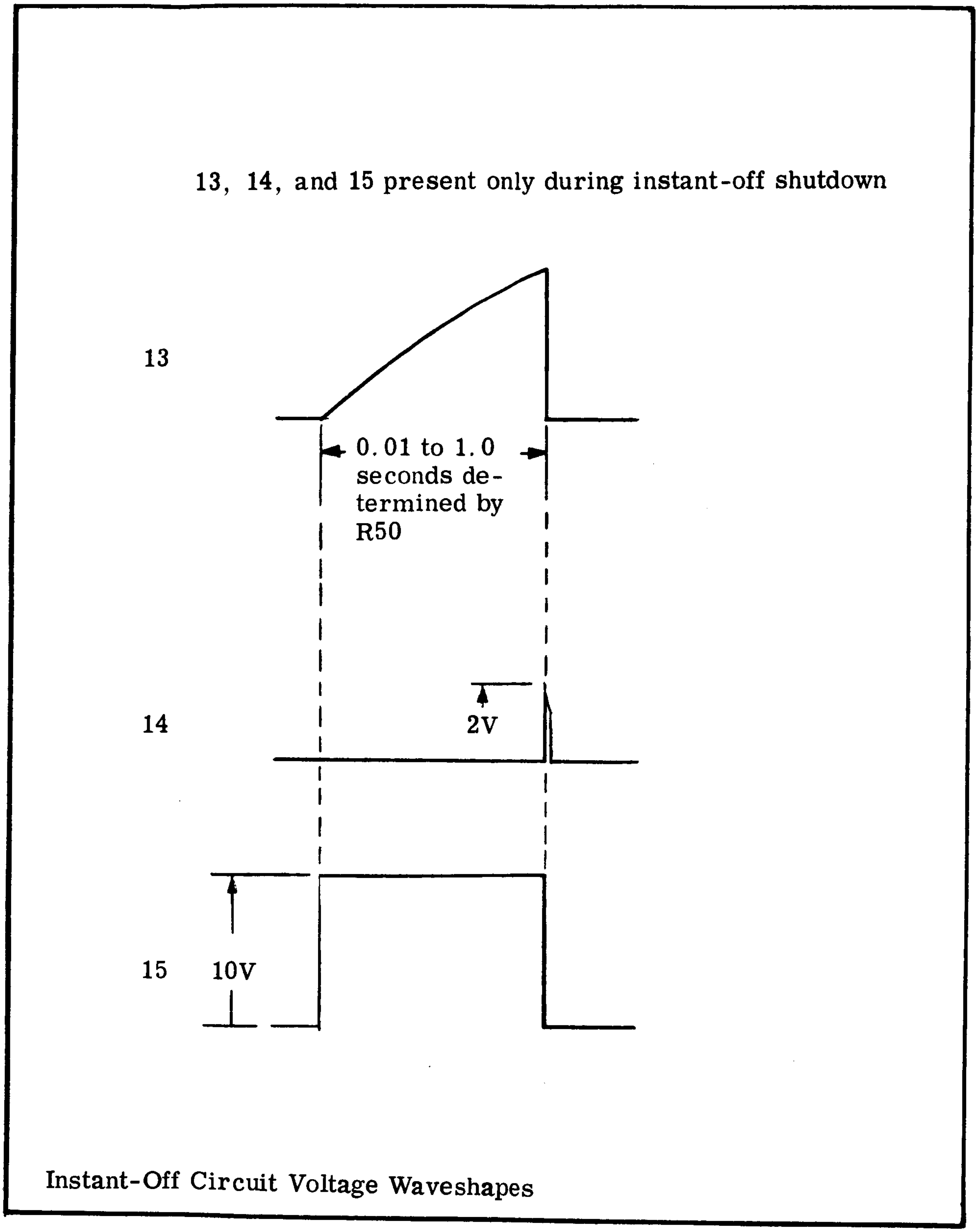
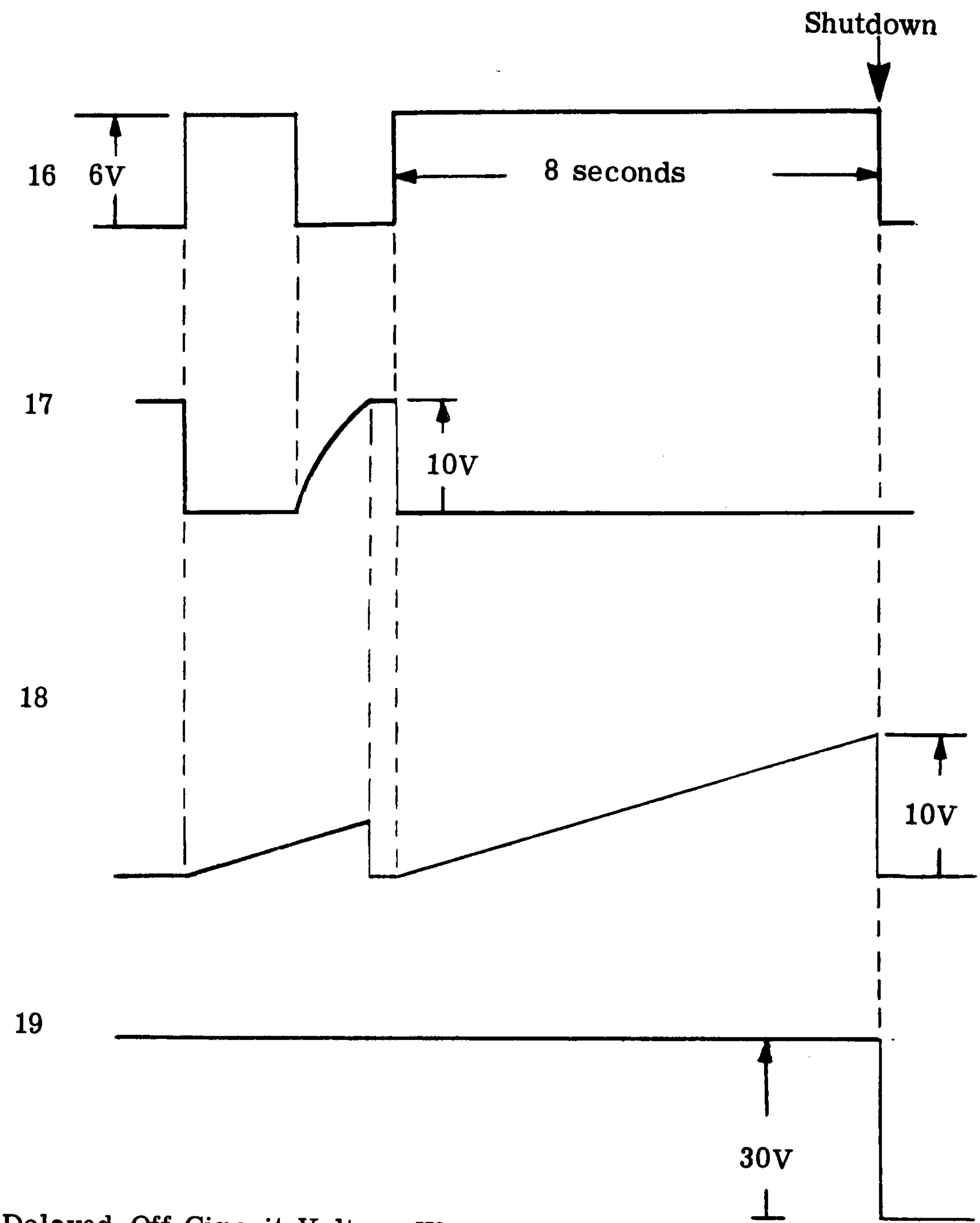


FIGURE 51. Operating Waveshapes - Continued

17, 18, and 19 present during overload signal application 16.

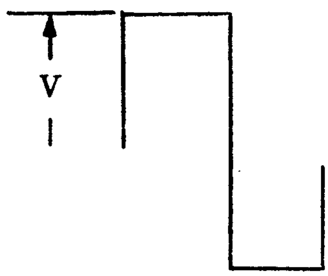


Delayed-Off Circuit Voltage Waveshapes

27 DC voltage proportional to the RMS value of V8 output voltage

FIGURE 51. Operating Waveshapes - Continued

23

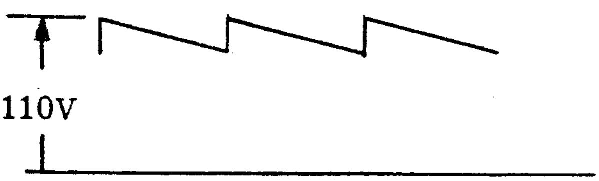


Voltage V decreases with increasing load
f = 2 kHz

Transformer Input Voltage - Neutralizer Vaporizer Supply

9 DC voltage - see volt-ampere characteristics

26

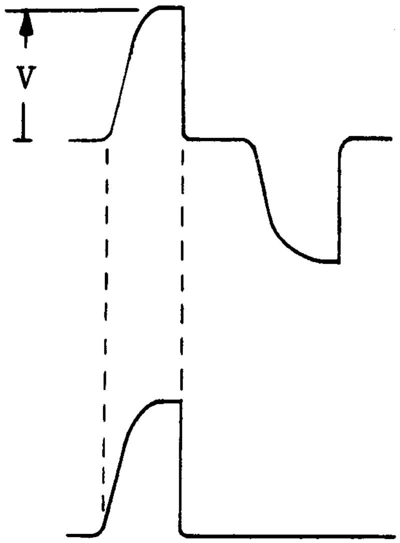


f = 2 kHz

Inverter-Spike-Suppressor Voltage Waveform

FIGURE 51. Operating Waveshapes - Continued

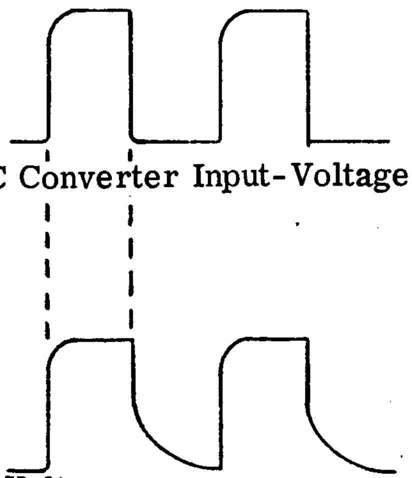
20 f = 2.5 kHz



53 f = 2.5 kHz

Voltage Waveshapes across magnetic amplifier - Neutralizer Cathode Supply

24



f = 5 kHz
Pulse width varies with pulse width of output voltage or current

RMS-DC Converter Input-Voltage Waveform

22, 36
28, 47
32, 49
34
39

f = 5 kHz
Pulse amplitude varies with amplitude of output voltage or current

Internal Voltage Waveshape - RMS-DC Converter

21 DC voltage proportional to RMS value of load current

27 DC voltage proportional to RMS value of load voltage

29 DC voltage proportional to load voltage

30 DC voltage proportional to load voltage

FIGURE 51. Operating Waveshapes - Continued

31	DC voltage proportional to load current
33	DC voltage proportional to RMS value of load current
35	DC voltage proportional to RMS value of load voltage
37	DC voltage proportional to RMS value of load voltage
38	DC voltage proportional to RMS value of load current
40	Normally 40 - 60 volts DC. Drops to zero volts at input voltages above 60 volts
41	Normally 40 - 60 volts DC
42	Filtered DC input. 40 - 60 volts DC
43	Regulated 10 volt dc supply voltage
44	Regulated 30 volt dc supply voltage
45	DC voltage proportional to V5 and V6 output voltage
46	DC voltage proportional to RMS value of load current
48	DC voltage proportional to RMS value of load voltage
50	Normally 0.1 volts. Rises to 0.7 volts when main input voltage drops below 40 volts
51	Normally zero volts. Rises to 10 volts during operation of instant-off circuit and during off time. When operation is resumed, decays to zero volts in 2 seconds
52	Normally 10 volts DC. Drops to zero volts when voltage 51 is greater than 1 volt

FIGURE 51. Operating Waveshapes - Concluded

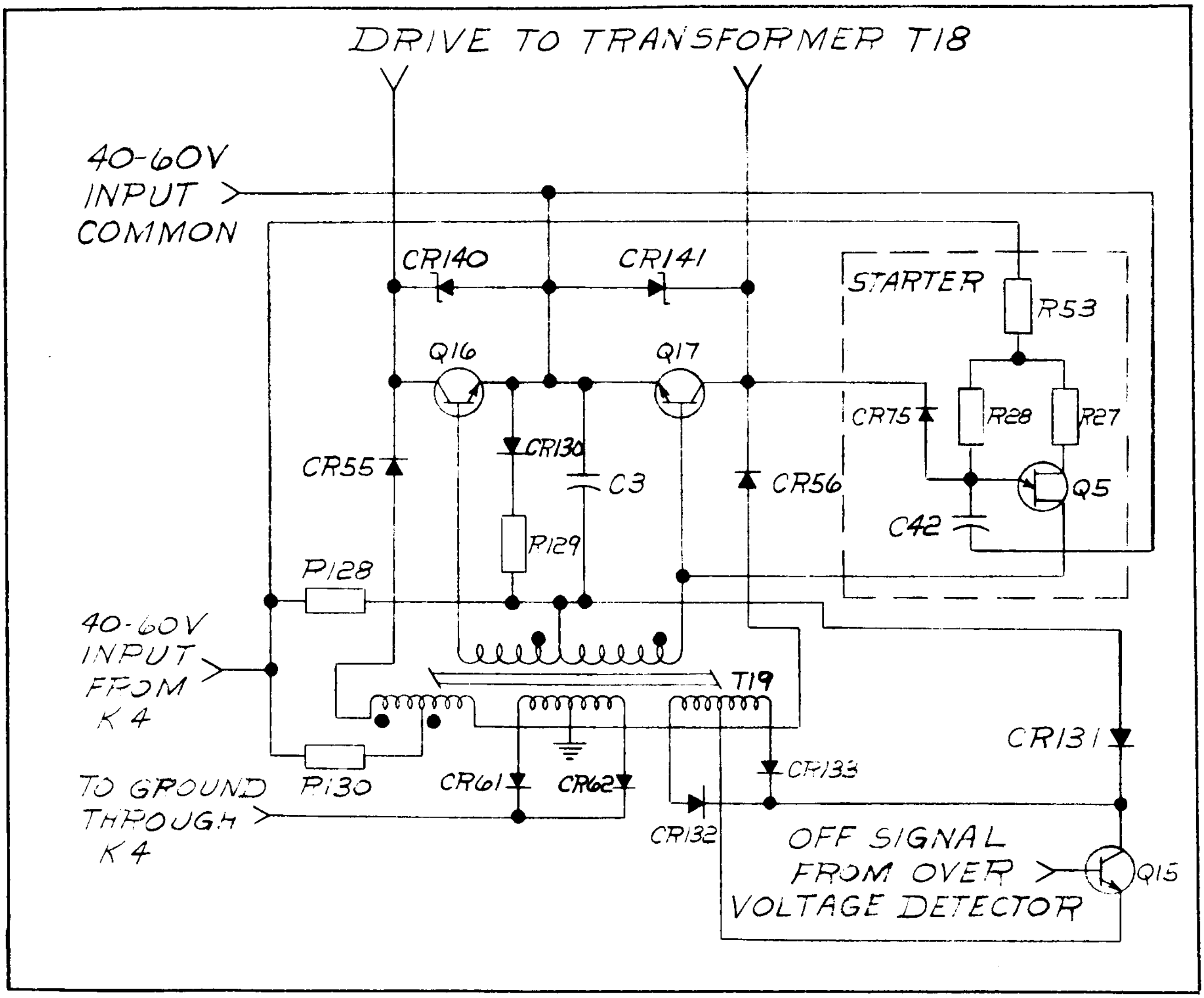


FIGURE 52. Schematic Diagram - Squarewave Oscillator

longer supplied, and the transistor turns off. The collapsing magnetic field which results causes an induced voltage in the secondary of T19 of opposite polarity such that the base of Q16 becomes positive. This turns on Q16 in the same regenerative manner as Q17 was turned on. At the same time, the charge on capacitor C3 provides a reverse bias to turn off Q17. This switching action is repeated periodically at the rate of 4 kHz, and results in a 2-kHz squarewave at the collectors of Q16 and Q17. One of the inherent characteristics of this oscillator is that the operating frequency is directly proportional to the input voltage. Thus, depending upon the dc input voltage, the operating frequency varies between 1.7 and 2.7 kHz.

A definite advantage is attributable to this type of operation, in that all magnetic components operate with a constant voltage-to-frequency ratio. As a result, the magnetic components are operated under optimum conditions regardless of the power conditioner input voltage.

Avalanche diodes CR140 and CR141 serve a dual purpose. As avalanche diodes, they protect transistors Q16 and Q17 against excessive voltages which generally occur during the switching interval. As ordinary diodes, they provide a path for inductive currents caused by the magnetic devices. An example of the latter is presented in the discussion of the power amplifier.

Oscillators of this type are often difficult to start under load. In order to ensure startup under all conditions, a starter circuit has been incorporated. When the 40 to 60 volt input is applied, a current flows through resistor R128 into the base of both Q16 and Q17 to input common. Diode CR130 prevents this current from being shunted by R129. The current partially turns on Q16 and Q17, making these transistors susceptible to electrical disturbances. The starter circuit, a unijunction transistor oscillator, provides a periodic discharge path for capacitor C42 which in this case includes the base-emitter junction of Q17. This action provides the electrical disturbance required to start the squarewave oscillator.

The pulse frequency of the starter circuit is much lower than the operating frequency of the squarewave oscillator. Thus, once oscillations begin, capacitor C42 is discharged through diode CR75 each time Q17 is on, resulting in a negligible voltage across C42.

Diodes CR55 and CR56 become necessary when the squarewave oscillator is used to drive transformer T18. These diodes prevent the voltages present on T18 from being applied to T19.

Power Amplifier. - A schematic diagram of the power amplifier is shown in Figure 53. Transistors Q1 and Q2 are the main power switches and are rated at 70 amperes and 200 volts. These transistors provide a squarewave drive to high-voltage transformer T1, which provides the output voltages required for the screen and the accelerator supplies.

The power amplifier utilizes controlled current feedback to provide base drive to Q1 and Q2 proportional to the collector current of these transistors. This allows maximum operating efficiency over wide load variations.

During normal operation, one of the power transistors is on while the other is off. At no time are both transistors on simultaneously. For a description of circuit operation, assume transistor Q1 is on, and that this condition was achieved by turning on transistor Q38. A current now flows from the 40 to 60 volt input into the center tap of T1. Current leaves the left side of T1, passes through current transformer T17, then, flows through two turns on transformer T2, and through Q1. As a result, the polarities on T2 are such that all dots are positive. Under these conditions, current flows into the base-emitter junction of Q1 of a magnitude proportional to the collector current. When the polarity of the squarewave oscillator reverses, transistor Q37 will turn on while Q38 will turn off. Since all dots on T2 were made to be positive due to current feedback, transformer T2 now sees a short circuit through Q37 and diode CR64. As such, T2 can no longer support any voltage with the result that base drive to Q1 no longer exists. Due to the storage time of Q1, however, collector current continues to flow for a short period of time. As soon as this current falls to zero, current flow through CR64 in the primary of T2 also falls to zero, allowing a voltage to be impressed across T2 due to the current flow from the 40 to 60 volt input, through R132 and Q37. The resulting polarities in the transformer are now such that all dots are negative. This causes transistor Q2 to become forward biased. The resulting collector current through Q2 (and T2) causes a regenerative current feedback to the base of Q2 until this transistor becomes saturated. The cycle is repeated in this manner at the frequency of the squarewave oscillator.

Diodes CR43 and CR44 together with capacitor C1 provide a bias voltage of approximately one volt which allows both transistors to be reverse biased during the switching interval. The reverse bias applied to the transistor being turned off greatly reduces the storage time and the turn-off time. Resistor R126 simply provides a discharge path for C1 when the power amplifier is turned off so that no reverse bias exists upon startup.

Diodes CR164 and CR165 perform the dual function of spike suppression and inductive current commutation. Although the electric engine contains

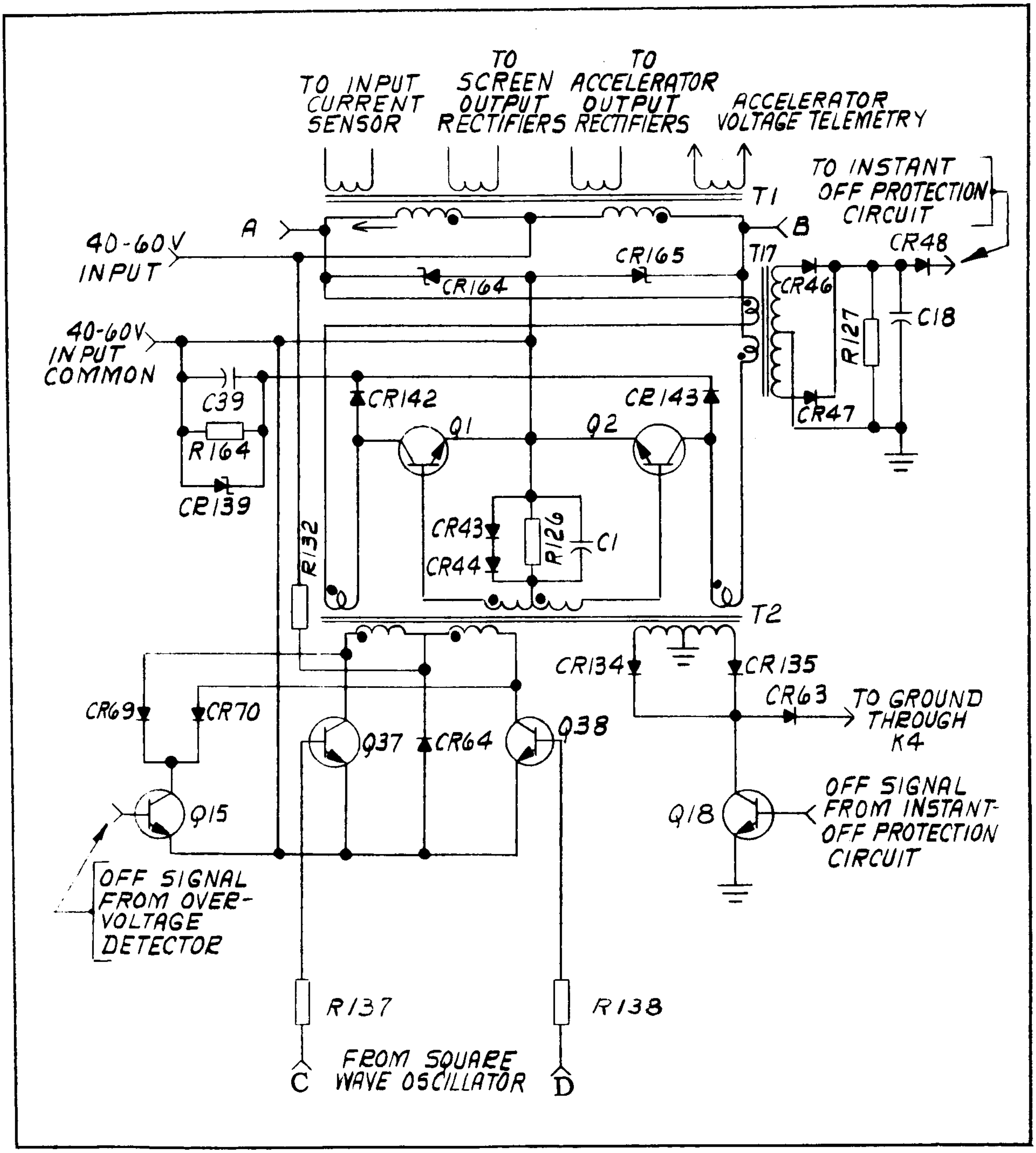


FIGURE 53. Schematic Diagram - Power Amplifier

essentially unity power factor loads, sufficient leakage inductance exists in the magnetic devices to cause inductive currents. For example, assume that transistor Q1 is on, causing an appropriate current flow through T1 as indicated by the arrow in Figure 53. When Q1 turns off, the primary of T1 becomes a voltage source which attempts to maintain the same current flow. The resulting voltage is coupled to the opposite half of the primary of T1, and causes a current flow through the 40 to 60 volt input capacitor to common, returning through diode CR165. It now becomes apparent that the coupling between halves of the primary must be very tight in order to minimize the spike voltages which appear across the transistors during turnoff.

The spike voltage just discussed are generally limited to a maximum value by avalanche diodes CR164 and CR165. It has been observed, however, that as the switching speeds of the transistors become greater, the spike voltages, which contain high frequency components, become increasingly difficult to suppress. This difficulty has been attributed both to the characteristics of the avalanche diodes and to the circuit wiring.

In an attempt to reduce the magnitude of the voltage spikes, a spike suppression network consisting of CR142, CR143, CR139, R164, and C39 has been incorporated. Spike voltages present on the collectors of Q1 and Q2 are conducted through diodes CR142 and CR143 to capacitor C39. During the absence of the spikes, resistor R164 partially discharges C39. Avalanche diode CR139 provides an absolute limit to the charge voltage on C39, thereby providing an absolute limit to the spike voltage. Although this circuit limits the magnitude of the spike to a lower voltage than the avalanche diodes across each transistor, the energy of the spikes are nevertheless dissipated in both cases. In addition, problem areas exist also in the spike suppression network. At higher switching speeds, circuit wiring again becomes important, as does the effective series resistance of capacitor C39. If the latter parameter is too high, the spike voltages can be observed across C39, but the capacitor will not charge to the peak spike voltage.

The power amplifier is shut down by one of two methods. Two independent shut-down circuits are required becauses of the isolated ground requirements of the power conditioner. In both cases, shut down is accomplished by shorting a winding on transformer T2. In one case, an over-voltage condition at the power conditioner input terminals causes transistor Q15 to turn on. In the other case, an over-current condition sensed by the instant-off circuit causes transistor Q18 to turn on. Shorting of transformer T2 for shutdown rather than removal of the drive signal is necessary since, under the latter condition, the power amplifier would continue to operate in a self-oscillating mode.

Since the overload capability of the power conditioner hinges on the power transistors, sensing of load current is accomplished by directly sensing the transistor collector currents. In this manner, a true indication of stress on the power conditioner is obtained. These currents are sensed by transformer T17, then rectified and filtered to provide a dc voltage proportional to transistor collector current. It is important in this application that capacitor C18 is relatively small, so that a time delay is not introduced.

The resulting signal is compared to a reference voltage in the instant-off circuit, which in turn shuts down the power conditioner by turning on transistor Q18 upon overload.

Power transformer T1 is the result of a major redesign effort following the insulation failures associated with the first two transformers. The final configuration was designed to minimize the intra-winding capacitance of the transformer secondary, and to reduce the maximum voltage gradients within the transformer to a level below the corona onset voltage.

To fulfill both of these requirements, the transformer was wound in segments on two machined coil forms. Figure 54 shows the various stages of the transformer assembly, while Figure 55 presents various views of the completed unit before potting.

The assembled transformer was potted by the Westinghouse Aerospace Division in Baltimore, Maryland. The process included a high temperature pre-bake of the transformer under high-vacuum conditions, which serves to remove moisture from within the windings. During the pre-bake period, the potting material was maintained at a high vacuum to remove entrapped air. Finally, potting was accomplished by immersing the transformer in the potting material while under vacuum, then applying a pressure of three atmospheres. As a result, a completely impregnated transformer was obtained that was as free of voids within the structure as the present state-of-the-art would allow.

<u>Feed Supply</u>. - The feed supply is a voltage regulated ac power source, providing a pulse-width-modulated output controlled by a magnetic amplifier. The ac input to this circuit is obtained from points A and B of the power amplifier. As such, the feed supply is disabled whenever the power amplifier is shut down.

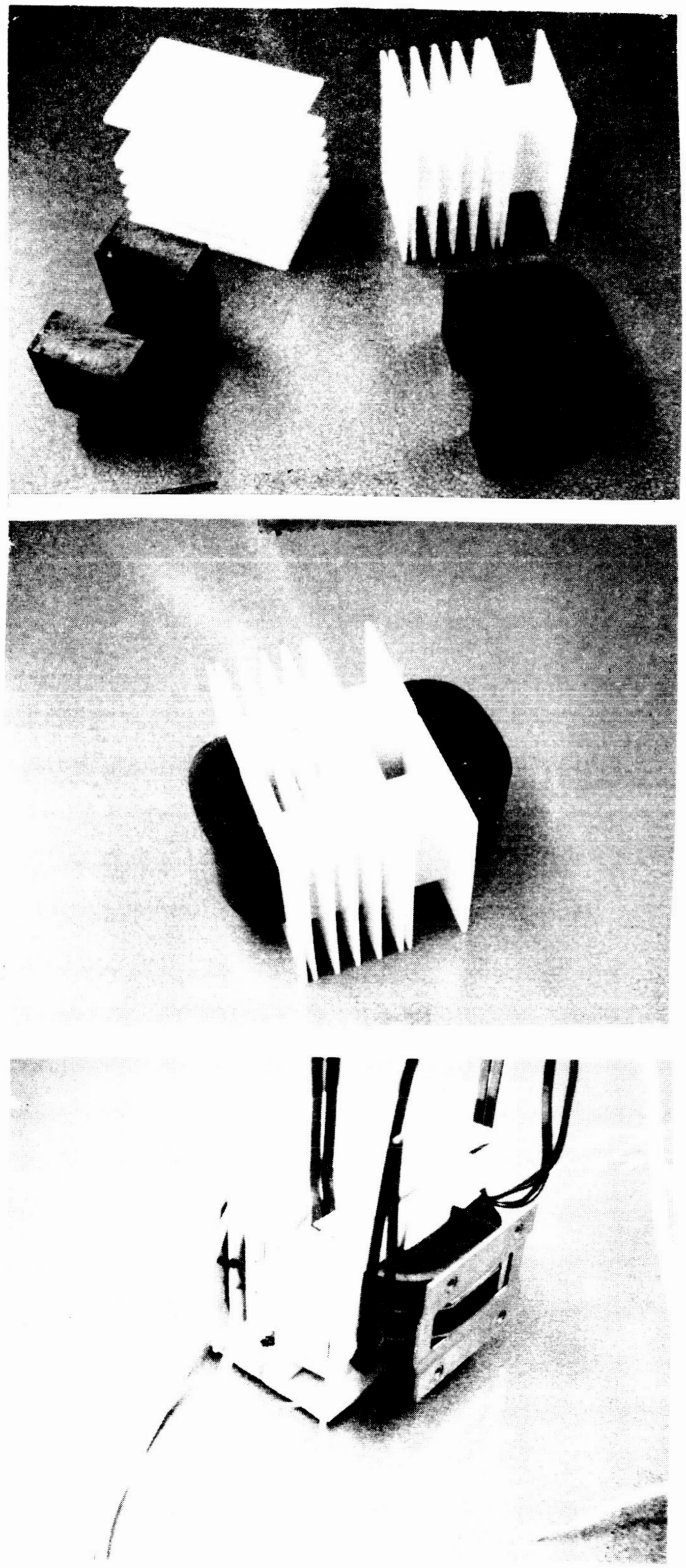


FIGURE 54. Various Views of High Voltage Transformer Before Potting

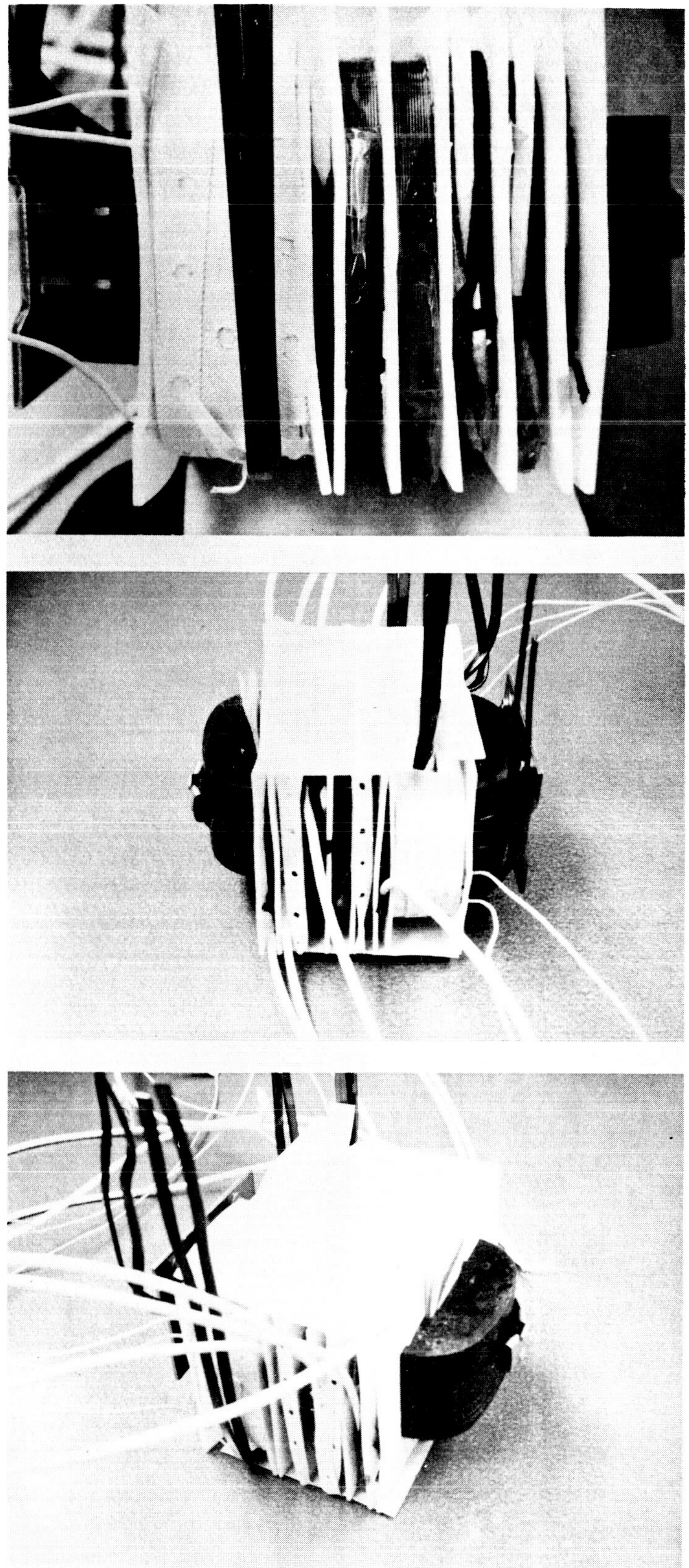


FIGURE 55. Various Views of Assembled High Voltage Transformer Before Potting

The magnetic amplifier AR2 is used in a full-wave self-saturating configuration. Electrically in series with the output transformer, it can support no voltage without the presence of a control current in winding number 4. Under these conditions, the entire cycle of the power-amplifier squarewave is applied to transformer T6. As the control current is increased, the cores in the magnetic amplifier are partially reset during the non-conducting half cycle. As a result, the magnetic amplifier can support an increasing portion of the applied squarewave. The portion supported by the magnetic amplifier is not applied to transformer T6, and the output of the feed supply is reduced.

Figure 56 illustrates a typical magnetic amplifier transfer characteristic. With no control current present, the average output voltage of a half-cycle is equal to the peak value of the squarewave. In this mode of operation AR2 remains saturated (Curve A, Figure 57). The control current exerts relatively little influence on the magnetic-amplifier output until its level reaches I_B, a value comparable to its exciting current. With a control current equal to I_B, operation corresponds to curve B in Figure 57. Curve C in this figure illustrates a typical B-H loop while operating in the control region of the transfer characteristic curve.

When the control current reaches I_C, operation is over the entire magnetization curve. At this time AR2 supports the entire cycle of the applied squarewave and the feed output is essentially zero. Should the control current exceed I_C, the magnetic amplifier would begin to saturate at the opposite end of the B-H curve. In a closed loop configuration, it is important that operation outside of the latter region is ensured. In this region, the polarity of the control loop is reversed, causing a regenerative effect which results in a complete loss of control.

In the feed circuit the control current for the magnetic amplifier is obtained from a tap on potentiometer R36. The voltage across R36 is a dc voltage proportional to the rms value of the feed output voltage and is obtained through transformer T7 by sensing the primary voltage of T6. The method whereby rms-to-dc conversion is accomplished is described in another section.

When the feed output voltage exceeds the desired level, the voltage at the tap of R36 exceeds the breakdown voltage of avalanche diode CR34. As a result, a control current flows through winding number 4 of AR2, and the feed output voltage is reduced to the required value.

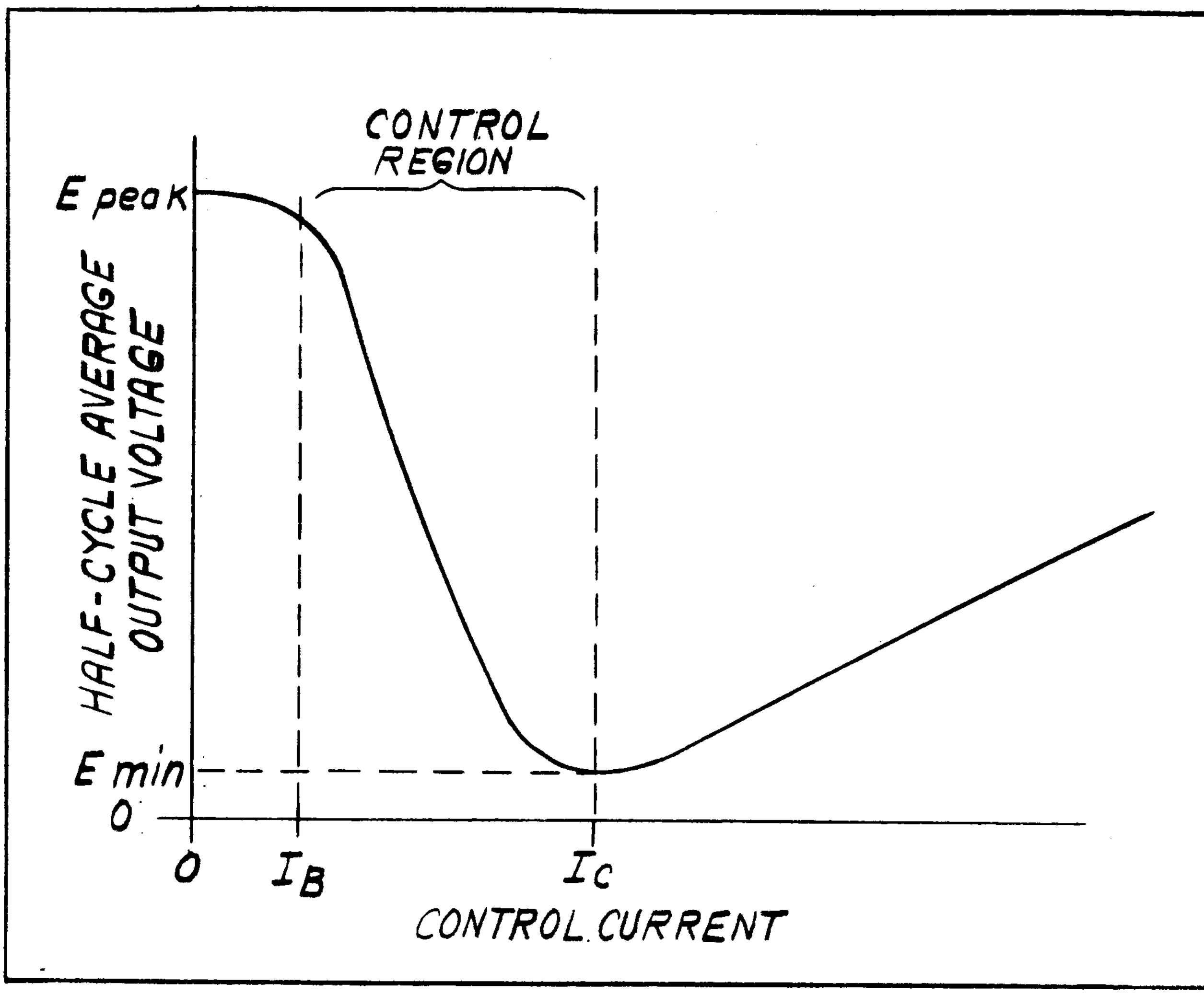
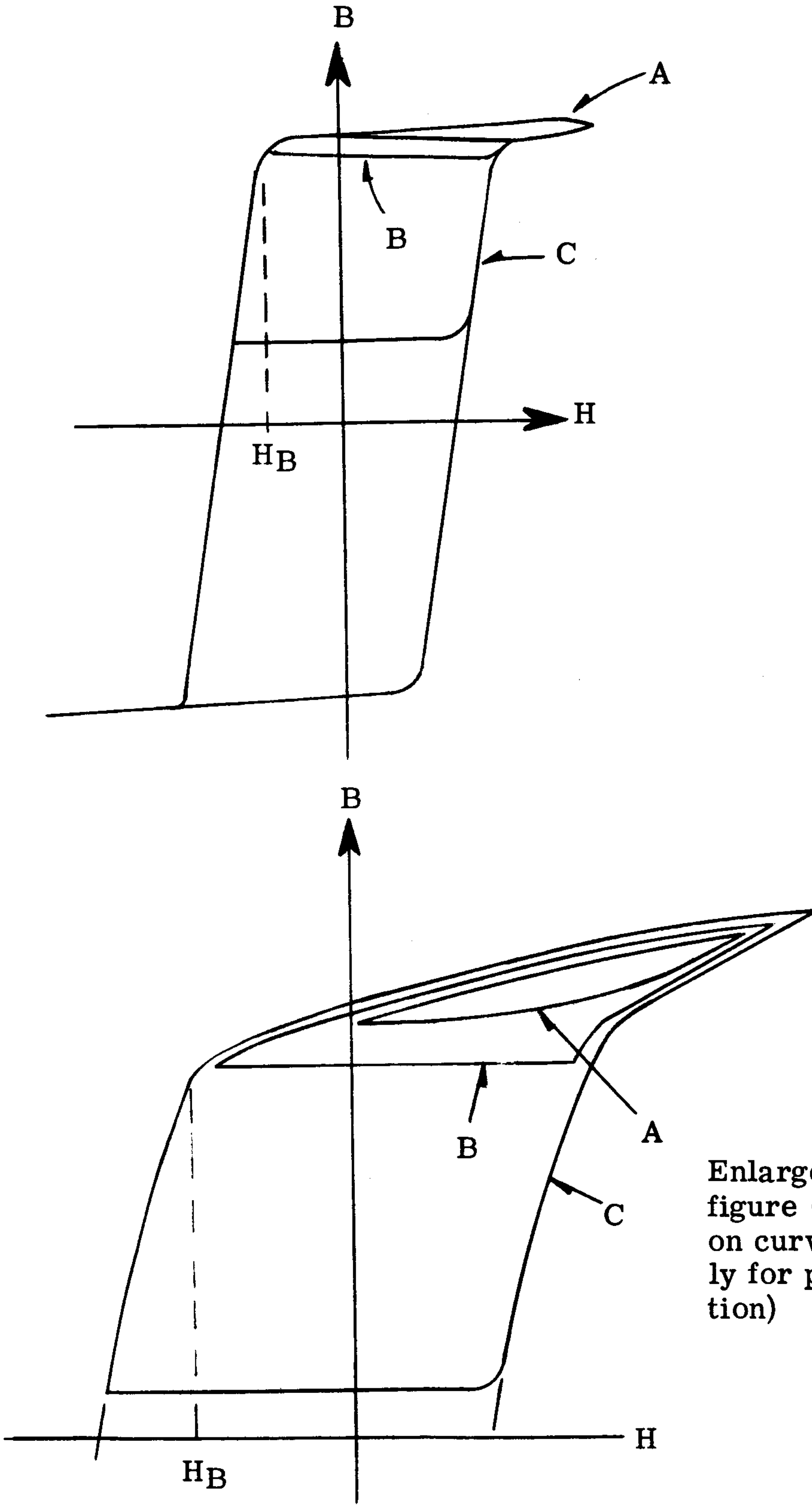


FIGURE 56. Typical Magnetic Amplifier Transfer Characteristic

Two additional control currents are required for proper operation of the power conditioner. When the dc input voltage falls below 41 volts, the feed supply output must be reduced. This has the effect of reducing the main power requirements of the electric engine, thereby reducing the load on the dc input supply. The dc input voltage is sensed by means of a voltage divider consisting of resistors R113 and R114 across the rectified output of transformer T18. This arrangement provides the required ground isolation.

During normal operation, the voltage at the tap of R114 exceeds the breakdown voltage of avalanche diode CR38. As a result, transistor Q6 in the feed circuit remains saturated. When the input voltage falls below 41 volts, CR38 no longer conducts, so that transistor Q6 turns off. The collector voltage of Q6 now rises, causing a current flow through CR8 into the



Enlarged view of upper figure (common points on curves shown separately for purposes of illustration)

FIGURE 57. Magnetic Amplifier B-H Operating Loops

control winding of AR2. This action retards the feed supply output as required.

Each time engine operation is interrupted, it is desirable for the feed supply to remain off for several seconds after engine operation is resumed. This is accomplished by the feed-off delay circuit. Each time the power amplifier is shut down by the conduction of Q18, a current flow through R143 and CR73 turns on transistor Q12 in the feed circuit. The resulting collector current also turns on Q13, which causes a current to flow through the control winding of AR2. When normal operation is resumed, Q18 turns off thereby removing base drive to Q12. Capacitor C22 must now discharge through the base-emitter junction of Q13, maintaining the control current in AR2. This discharge requires approximately 2 seconds, at which time the feed supply output rises to its regulated level.

Winding number 3 on AR2 provides a bias current equivalent to I_B as illustrated in Figure 56. This reduces the current requirements of the control winding, and provides more predictable operation with variations in ambient temperature.

Winding number 5 receives a control current when the screen current exceeds a preset level. Retarding the feed output in this manner maintains the desired level of screen current, thereby providing closed-loop control of engine thrust.

Winding number 6 consists of a small number of shorted turns, and performs a twofold function. The response time of the magnetic amplifier is increased, resulting in stable closed-loop operation. In addition, the shorted turns tend to reshape the B-H curve of the magnetic amplifier, eliminating any regions of negative slope. This negative slope would be indicated by a positive slope in the control region of the transfer characteristic shown in Figure 56, and results in the phenomena known as triggering, characterized by a loss of control in this region.

The secondary of transformer T6 consists of two identical windings. Depending upon the load requirements, the windings can be connected in series or in parallel to obtain the desired output voltage. Small adjustments of the output can be made with potentiometer R36.

Load current delivered by the feed supply is sensed by current transformer T5. The sensed current is a pulse-width-modulated squarewave, and is converted to a proportional dc signal by an rms/dc converter as described in another section.

Cathode Supply. - The cathode supply is a current limited ac power source which provides a pulse-width-modulated output controlled by a magnetic amplifier. Operation of the cathode circuit is essentially the same as that of the feed supply, although the configuration of the power circuit is somewhat different. The feed output transformer T6 was fed by the voltage developed between points A and B of the inverter power amplifier with the magnetic amplifier in series. In this arrangement, the primary of the main power transformer T1 was required to carry the load power of the feed supply. Since the feed supply output power was relatively low, this configuration was quite satisfactory. The cathode supply, on the other hand, must provide a fairly large amount of power to the load. So as not to burden the main power transformer with this additional power, input power to the cathode supply is provided utilizing a form of current drive. In this arrangement, dc input current flows directly into the center tap of the cathode power transformer, through the magnetic amplifier, and to input common through transistor Q1 or Q2. Although this arrangement prevents increasing the size of transformer T1, it does require a center-tapped output transformer (T13) with a consequent increase in size.

Cathode load current and voltage is sensed on the primary side of T13 by means of T11 and T12 respectively. Once again, the pulse-width-modulated signals are converted to proportional dc voltages by an rms-to-dc converter. Potentiometer R79 applies a portion of the current signal to avalanche diode CR98. When the load current reaches a preset rms value, the voltage at the tap of R79 will be greater than the breakdown voltage of CR98. The resulting current flow through this diode will cause transistor Q36 to turn on, causing a current flow into the control winding (winding number 4) of AR4. In this manner the rms value of the load current is maintained below a preset level. It should be noted here that the control winding also receives a signal from the anode circuit. In this manner the cathode output is retarded when the anode current rises above a preset level.

Since the engine cathode is floating at a potential of 3000 volts, cathode load current and voltage are sensed in the primary side of the output transformer. This eliminates the need for additional high-voltage transformers and the inherent high-voltage insulation problems. Although the resulting circuit operation is satisfactory, errors are introduced into the current and voltage sensing circuits in this configuration. The current sensing transformer, for example, senses not only load current, but also the exciting current of the output transformer which, in some cases, is appreciable. The voltage sensing transformer, quite sensitive to changes in voltage at the primary of T13, does not observe the changes in secondary voltage caused by load variations and the associated transformer losses. The errors introduced in this manner are noticeable in the telemetry calibration data presented in the appendix.

While the prime function of the cathode circuit is to deliver a constant rms current to the load, it is important to discuss the instantaneous peak currents. Figure 58 shows the change in the peak currents delivered by the power conditioner as the output pulse width varies. In all cases shown, the rms value of the waveform is constant. From these curves it is evident that the peak currents can be very high, and it is these peak currents that determine the rating of the power switching transistors.

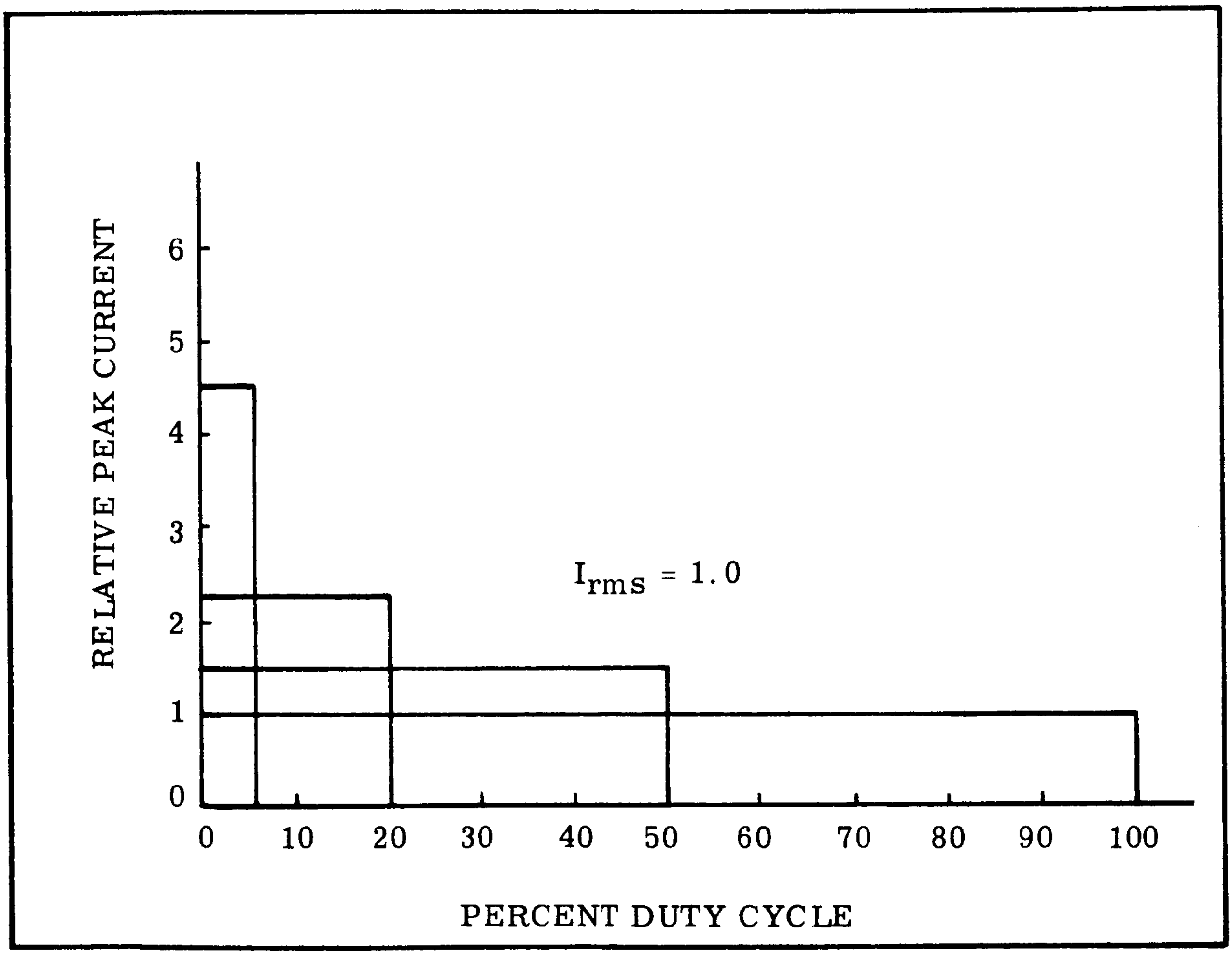


FIGURE 58. Effect of Pulse-Width-Modulation on Peak Currents

As the duty cycle of the output wave approaches zero, the magnitude of the peak current approaches infinity. Obviously, the peak currents must be limited in a practical system. This limiting is accomplished by the inherent winding resistance of the magnetic amplifier and the output transformer, and by the relatively loose coupling between the primary and secondary of the power transformer.

Avalanche diode CR99 connects the cathode-current sensing circuit to the delayed-off bus. When an overload exists on the cathode supply for a period of eight seconds, the delayed-off circuit shuts down the entire power conditioner.

Anode Supply. - The anode supply is an unregulated dc power source capable of supplying one of four selected output voltages. The output is characterized by a high no-load voltage required for initial startup of the engine.

The anode supply is protected against overloads by the instant-off circuit, which instantaneously shuts down the power amplifier for a predetermined period of time.

The anode circuit is current driven by the power amplifier transistors in the same manner as the cathode circuit. The output is selected by changing taps on the primary side of the output transformer. Tap changing is accomplished by selectively energizing three latch relays, K5, K6, and K7.

The output of transformer T16 is full-wave rectified and filtered by diodes CR119 and CR120 and capacitor C20. An additional winding on T16 feeds a conventional voltage doubler circuit which in turn fulfills the high no-load voltage requirement.

Transformer T15 senses the anode load voltage on the primary side of T16. The output of T15 is rectified and filtered and provides telemetry information on anode voltage. It should be noted that the high no-load voltage is not reflected back to the primary of T16, and as such is not included in the telemetry signal.

Transformer T14 senses the anode load current, again on the primary side of the output transformer. The output of T14 is rectified and filtered and provides a signal for telemetry, for instant-off protection, and for control of the cathode output. The telemetry output is obtained from a voltage divider consisting of R93 and R94, and is limited by CR113.

Avalanche diode CR116 provides the reference level for instant-off protection. When anode load current becomes excessive, the voltage across resistor R91 will become greater than the breakdown voltage of CR116. The resulting current through CR159 trips the instant-off circuit thereby disabling the power amplifier stage. Control of the cathode output is obtained by selection of one of three adjustable current signals available at the taps of R65, R92, and R154. The desired tap is selected by means of latching relays K2 and K3. When the anode current reaches a specified level, the tap voltage will be greater than the breakdown voltage of avalanche diode CR112. The resulting current flow turns on transistor Q33, which in turn provides a control current in magnetic amplifier AR4, thereby reducing the cathode output.

Screen Supply. - The screen supply is an unregulated dc power source providing a positive high-voltage output. The supply is self protected against overloads by the instant-off circuit, which senses screen load current by sensing the collector current of the main power transistors Q1 and Q2.

The high voltage output from transformer T1 is rectified by a full-wave bridge consisting of diodes CR57 through CR60. Each diode is actually a number of diodes connected in series to obtain the required reverse breakdown voltage. They are packaged in a three-terminal configuration which comprises one half of the full-wave bridge. The output of the bridge is filtered by capacitor C23, which discharges after shutdown through R15 and R16.

The remaining components provide current and voltage sensing for telemetry and control purposes. The screen voltage telemetry signal is obtained from the voltage divider consisting of R15 and R16. Since the high output voltage necessitates high resistance values, the telemetry output impedance is reduced by emitter follower transistor Q8. Diode CR129 limits the magnitude of the voltage at the output terminal.

It should be noted that, while the screen supply is referenced to engine common, the screen voltage telemetry signal is referenced to telemetry ground. Although this arrangement provides a very simple means of obtaining the telemetry information, it requires a good external interconnection of both grounds for proper operation.

Screen current for telemetry and delayed-off protection is sensed by transformer T3, which senses load current before it is rectified. The resulting signal is rectified and filtered to obtain a smooth dc signal. Resistor R21 provides isolation between the output of T3 and the telemetry terminal. As such, the telemetry output may be shorted to ground without affecting the voltage developed across R22. For this reason the voltage developed across R22 rather than the filtered output is applied to the delayed-off bus through CR17.

Resistor R17, electrically in series with the screen supply, provides a signal voltage proportional to load current for control of the feed supply. This signal could as well have been obtained from the output of T3 with few circuit modifications, although neither configuration appears to have an advantage over the other.

The signal voltage developed across R17 is actually a function of the resistance of R17 in parallel with the series combination of R18 and R13 or R14. As such, the latter two resistors may be varied to control the developed voltage. Either potentiometer, therefore either of two signal levels, may be selected by remote command of relay K1. The resulting voltage developed across the resistor network is applied to avalanche diode CR15. When the screen current exceeds a predetermined level, the current through CR15 flows through winding number 5 of AR2, the feed circuit magnetic amplifier, reducing the feed supply output proportionately.

Accelerator Supply. - The accelerator supply is an unregulated dc power source which provides a negative high-voltage output. The accelerator supply, like the screen supply, is self-protected against overloads by the instant-off circuit, which senses the collector current of main power transistors Q1 and Q2.

The output of transformer T1 is rectified and filtered by a high-voltage bridge assembly and filter capacitor identical to that used in the screen supply. Capacitor C24 discharges after shutdown through resistor R6.

Accelerator load current is sensed by means of two dropping resistors, R24 and R25, located in series with the grounded side of the accelerator supply. The total voltage drop, sensed through R23, provides telemetry information at low levels of accelerator current. A portion of this signal at the tap of R24 and R25 provides telemetry information through R1 at high levels of accelerator load current. Diodes CR20 and CR21 limit the magnitude of the total voltage during overloads on the accelerator supply.

A portion of the total voltage present at the tap of R10 and R20 is fed to the delayed-off bus via diode CR30. Although the accelerator supply is capable of supplying surge currents as high as those in the screen supply, continuous overloads on the accelerator supply for periods exceeding eight seconds cause complete shutdown of the power conditioner by the delayed-off circuit. As in the screen supply, operation of the accelerator current sensing circuit, referenced to telemetry ground, requires an external connection between telemetry ground and engine common.

The output of winding number 3 on transformer T1 is rectified and filtered to provide a telemetry signal proportional to the accelerator output voltage. The circuit provides the required signal isolation, but is insensitive to losses in the accelerator supply. As a result, an increase in accelerator load current causes a decrease in the accelerator output voltage, while the telemetry voltage remains constant.

Neutralizer Cathode Supply. - The neutralizer cathode supply is a current-limited ac power source which provides a pulse-width-modulated output waveform controlled by a magnetic amplifier.

The power circuit is identical to that of the feed supply, except that the input to the circuit is obtained from the squarewave oscillator, points C and D on the schematic. This arrangement allows continuous operation of the neutralizer supplies regardless of interruptions in the high voltage supplies. Load current is sensed by transformer T8 in the primary of the output transformer.

The resulting signal is rectified and converted into a dc voltage proportional to the rms value of load current as described in a later section. The desired dc voltage is available at the emitter of transistor Q24. This voltage is used for delayed-off protection, for telemetry, and for current limiting. It is fed to the delayed-off bus through isolating diode CR80. The telemetry output is obtained from voltage divider resistors R67 and R68. The current limiting signal is taken from the tap of R69 and applied through R102 to avalanche diode CR79. Load currents above a predetermined level cause the tap voltage to exceed the breakdown voltage of CR79, resulting in a control current through winding number 4 of AR3. This control current maintains the rms load current at the desired level.

In this circuit, the magnetic amplifier bias current was applied directly to the control winding rather than to a separate winding to determine the possibility of eliminating one winding. No change in performance has been observed using this arrangement at room ambient temperatures, although a final decision must be based on tests conducted over temperature extremes.

The neutralizer cathode output voltage is sensed by transformer T9 on the primary side of the output transformer. Once again, this arrangement is insensitive to variations in load voltage due to transformer losses. Operation of the rms-to-dc conversion in the voltage sensing circuit is described in another section.

Neutralizer emission current is sensed by means of the voltage developed across resistor R8. Diode CR144 limits this voltage in the event of arcing between the high-voltage supplies and the neutralizer cathode terminals. The combination of R7, C44, and CR127 provide filtering and voltage limiting of the telemetry signal. The two terminals located between the secondary of T10 and resistor R48 are jumpered during normal operation. The terminals provide a means of introducing an external power supply to bias the entire neutralizer assembly. This bias appears to be desirable while conducting engine tests in a vacuum tank.

With the introduction of a bias supply, the protection afforded by diode CR144 against high voltage arcs is in doubt. As a result, diode CR161 in series with CR166 was added between terminal V7 and chassis ground. By using two avalanche diodes back to back, protection against positive and negative arcs is provided, while allowing the neutralizer assembly to be biased either positively or negatively by means of an external supply.

Neutralizer Vaporizer Supply. - The neutralizer vaporizer supply is a current-limited ac power source which provides a pulse-width-modulated output waveform controlled by a magnetic amplifier. Operation of this supply is very similar to that of the neutralizer cathode supply. A detailed description of this circuit will therefore not be repeated.

In the neutralizer vaporizer supply, load current is sensed in the secondary of the power transformer. With the resulting absence of exciting current in the sensing circuit, error was greatly reduced. The improvement in performance is evident in the shape of the volt-ampere characteristics curve.

Avalanche diode CR162 in series with CR166 provides protection in the event of high voltage arcing.

Neutralizer Bias Supply. - The neutralizer bias supply is an unregulated dc power source characterized by a high source impedance. This supply is located on the same circuit board as the neutralizer vaporizer supply.

The required high output impedance is provided by inductor L2 located on the primary side of T22. The output of T22 is rectified by a full-wave bridge and filtered by capacitor C45. As the load on the bias supply is increased, the increasing load reflected back to the primary of T22 causes a proportional increase in the IX_L drop across L2. This drop is non-dissipative, which provides a distinct advantage over a resistive dropping element, but produces a non-linear volt-ampere characteristic. Whether this non-linearity is tolerable during engine operation remains to be determined.

Since the voltage at the primary of T22 is proportional to load voltage, voltage sensing transformer T23 is located at this point. The output of T23 is rectified, filtered, and amplified, and provides a signal for telemetry and for control of the neutralizer vaporizer supply.

Proper engine operation requires that the neutralizer vaporizer output be reduced to zero when the neutralizer bias voltage falls below one of four preset voltage levels. These levels are set by potentiometers R64, R73, R76, and R95, and are selected by remote command by means of latching relays K8 and K9. The reference voltage is provided by the voltage divider consisting of resistors R81 and R150. When the voltage at the tap of the selected potentiometer (therefore the voltage at the base of Q31) becomes greater than the voltage across R150, a current flows into the base-emitter junction of Q31. This causes the collector voltage of Q31 to decrease, thereby removing base drive from Q32. As Q32 turns off, control current flowing through winding number 4 of AR5 decreases, allowing the neutralizer vaporizer supply to turn on. As the neutralizer bias voltage decreases below the preset level, the procedure reverses and the neutralizer vaporizer supply turns off.

Instant-Off Protection. - The function of the instant-off circuit is to provide protection for the inverter power amplifier during overloads on the screen, the accelerator, or the anode supply. Upon sensing an overload, the instant-off circuit instantaneously shuts down the power amplifier for a predetermined period of time, after which normal operation is resumed.

The circuit is shown schematically in Figure 59. Its operation is essentially that of a mono-stable multivibrator, changing state upon application of an input pulse, and remaining in this quasi-stable state for a specified period of time. Transistors Q19 and Q20 form a latch circuit. Upon receipt of an input pulse to the base of Q19, collector current in this transistor turns on Q20. As a result, collector current through Q20 flows through R26, R151, CR11, and into the base of Q19,

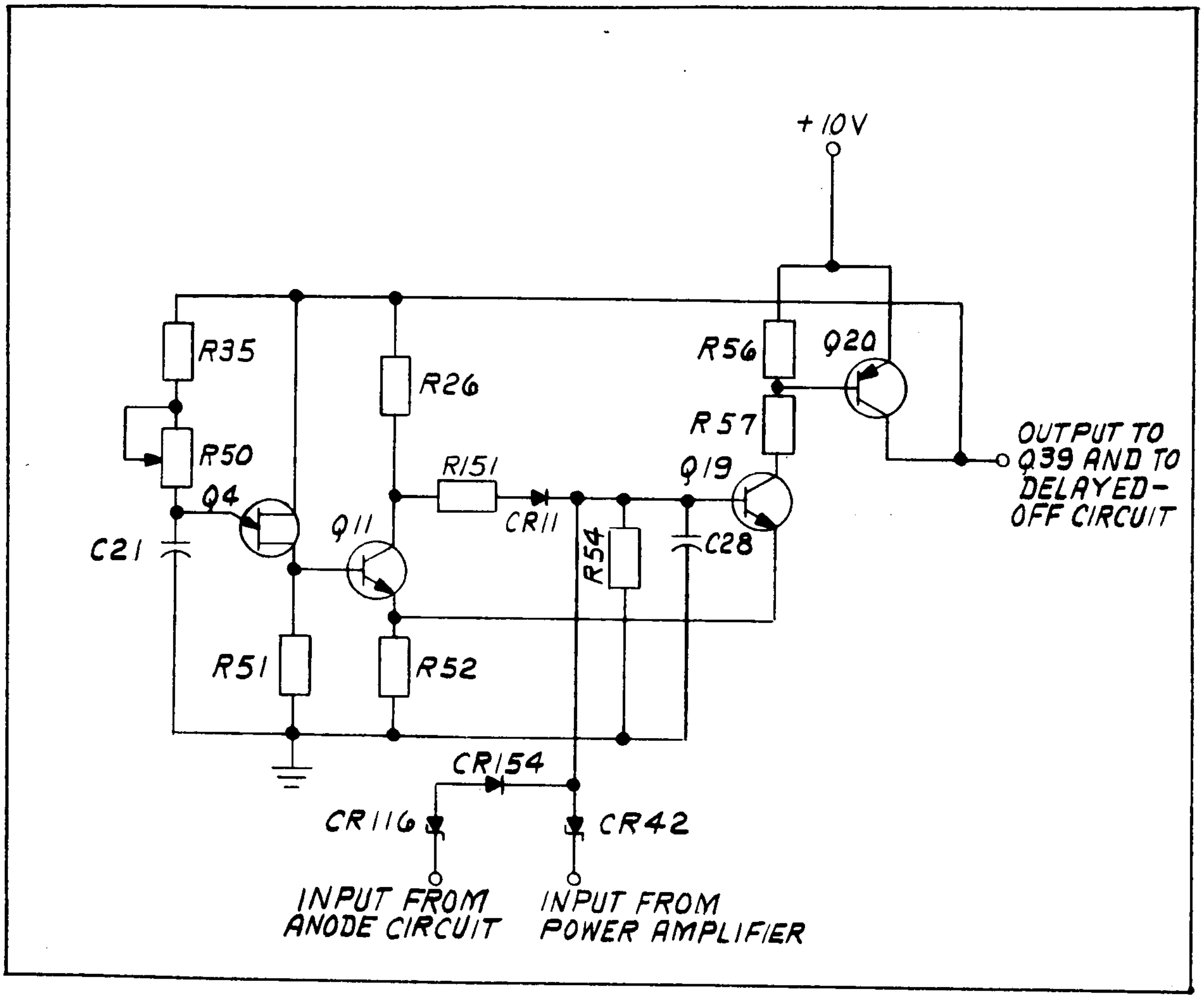


FIGURE 59. Schematic Diagram - Instant-Off Protection Circuit

thereby causing Q19 to remain on. During this time, the collector voltage of Q20 provides power to the unijunction oscillator, consisting of Q4 and associated components. Capacitor C21 now charges through R35 and R50. When the capacitor voltage reaches the firing voltage of Q4, C21 discharges through Q4 and R51, producing a voltage pulse across R51. This pulse momentarily turns on transistor Q11, which in turn removes base drive to Q19, returning the latch circuit to its original state.

Potentiomenter R50 serves to adjust the charging rate of capacitor C21, thereby providing an adjustment of the instant-off time period between 0.01 and 1.0 seconds.

During the instant-off interval, the output of Q20 provides base drive through R152 to Q39 and Q18. This disables the inverter power amplifier as described previously. The output of Q20 is also sensed by the delayed-off circuit, which disables the entire power conditioner unit upon repetitive application of instant-off pulses at intervals of less than 2 seconds. Operation of the delayed-off circuit is described in the following section.

Delayed-Off Protection. - The delayed-off circuit provides protection for the power conditioner against continuous overloads. Upon existance of a continuous or a pulsed input for a period greater than eight seconds, the delayed-off circuit de-energizes the power conditioner. Pulsed signals are ignored by this circuit unless the pulse repetition rate exceeds 0.5 pulses per second.

A schematic diagram of the delayed-off circuit is presented in Figure 60. During normal power conditioner operation, transistor Q29 is off, and capacitor C38 is charged to the breakdown voltage of avalanche diode CR138 with the result that Q28 is on. As such, no base drive is received by transistors Q26 and Q27. Upon application of a fault signal, transistor Q29 turns on, immediately discharging capacitor C38. As a result, transistor Q28 turns off, allowing capacitor C37 to charge at a rate determined by the RC time constant of C37 and R160. Capacitor C37 continues to charge upon removal of the fault signal until capacitor C38 charges to the breakdown voltage of CR138, in this case determined by the values of C38 and R162. Thus a pulsed input that is repeated within 2 seconds allows capacitor C37 to charge continuously, while the absence of a pulse for a period greater than two seconds will cause capacitor C37 to discharge.

When the voltage across C37 reaches the breakdown voltage of CR137, transistors Q27 and Q28 are turned on, energizing one coil of latching relay K4. The resulting contact action, indicated by the direction of the arrow,

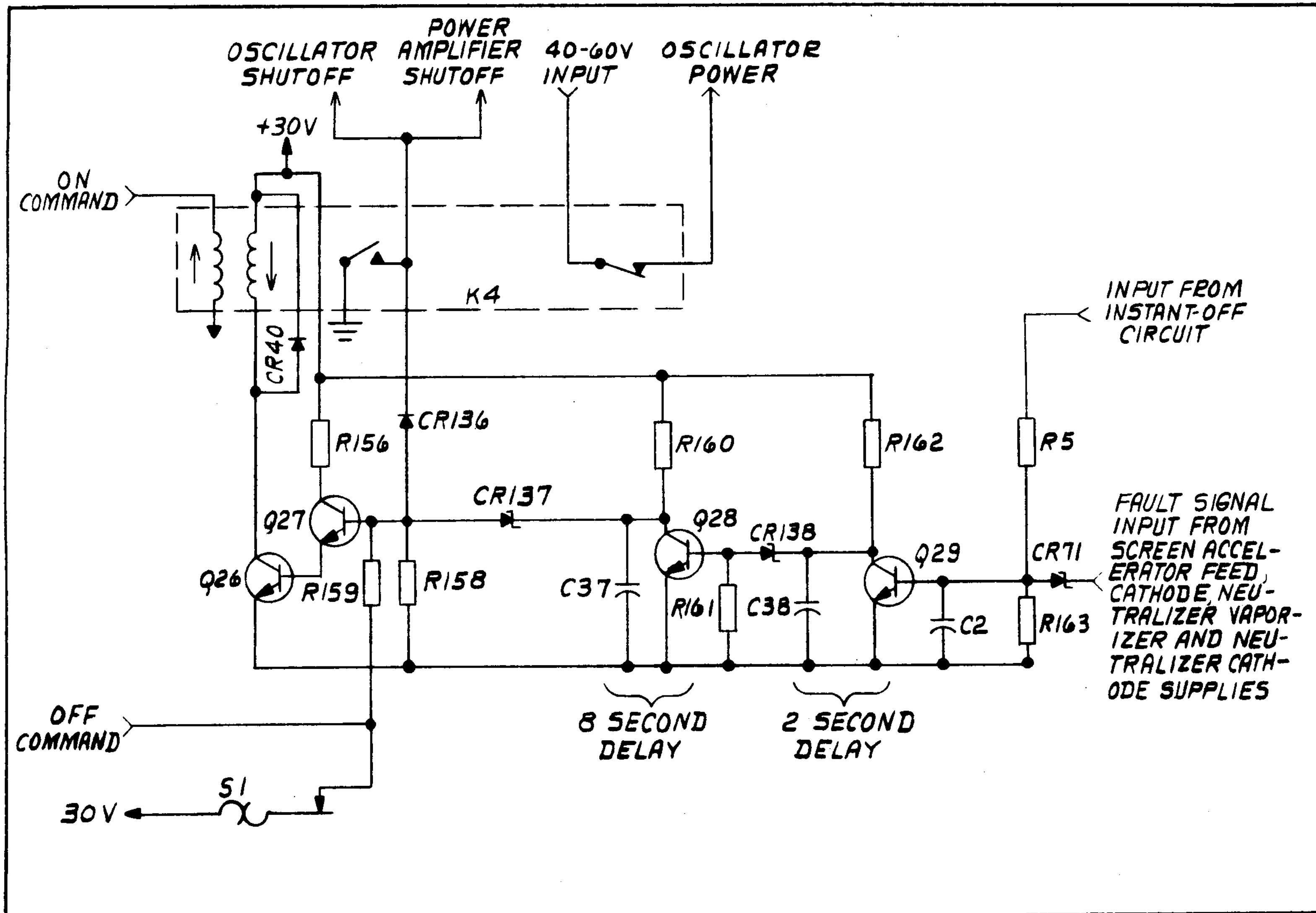


FIGURE 60. Schematic Diagram - Delayed-Off Protection Circuit

shorts one transformer winding each on oscillator transformer T19 and power-amplifier transformer T2, and interrupts the dc input power to the oscillator.

A thermostatic switch, represented as S1 in the schematic, is mounted on the heatsink of power transistor Q2. In the event the heatsink temperature rises above 100° C, S1 will close, thereby securing the power conditioner.

RMS/DC Conversion. - The control and telemetry functions of the power conditioner require dc signal voltages proportional to the output voltage and current of each individual supply. In the case of the ac supplies, the sensed variable is a pulse-width-modulated ac squarewave. This squarewave must be converted to a dc signal proportional to the rms value of the variable. A schematic diagram of the circuit used to accomplish this conversion is shown in Figure 61. The output of the sensing transformers is rectified and applied to the input of the rms/dc converter. In the case of the current sensing transformer, an emitter-follower transistor is included to provide a low impedance output. The applied waveform is a positive going squarewave varying in width and amplitude. Figure 62 shows the average value of this waveform as a function of pulse width B. Also shown is the rms value of the same waveform.

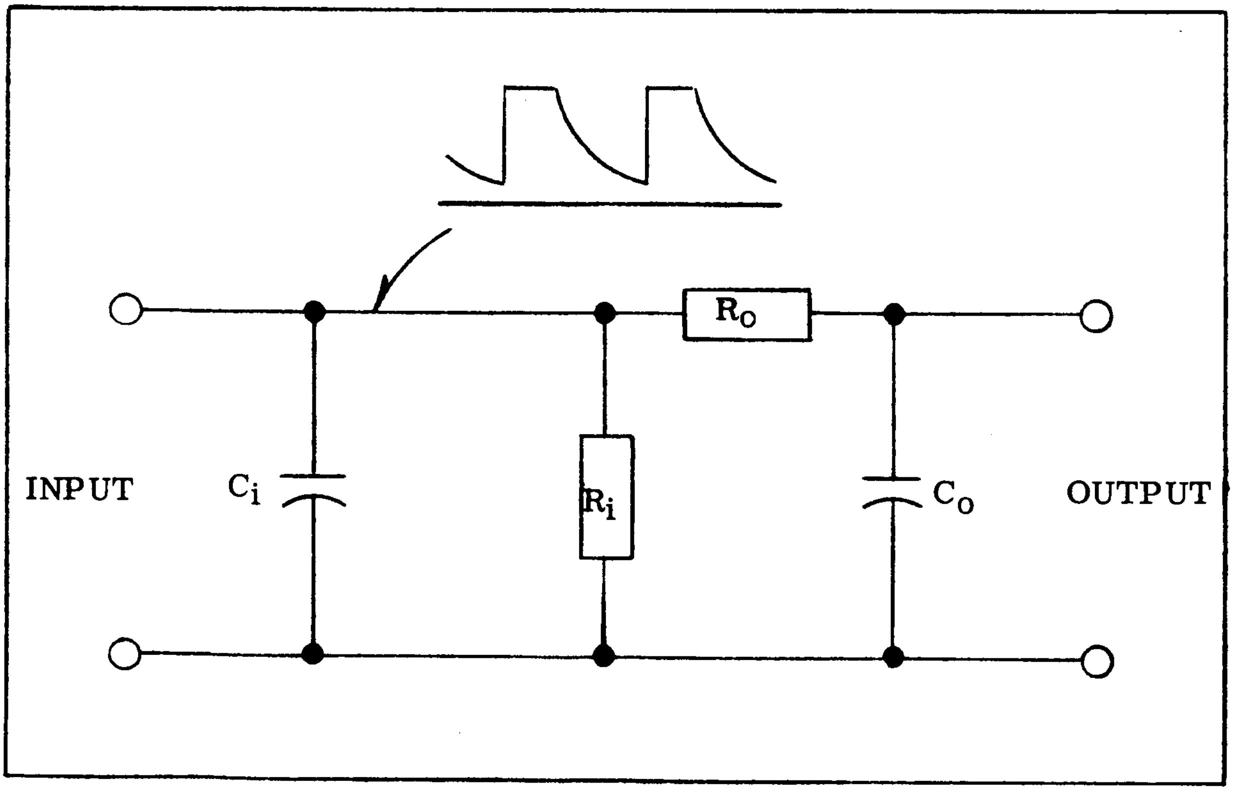


FIGURE 61. Schematic Diagram - RMS/DC Converter

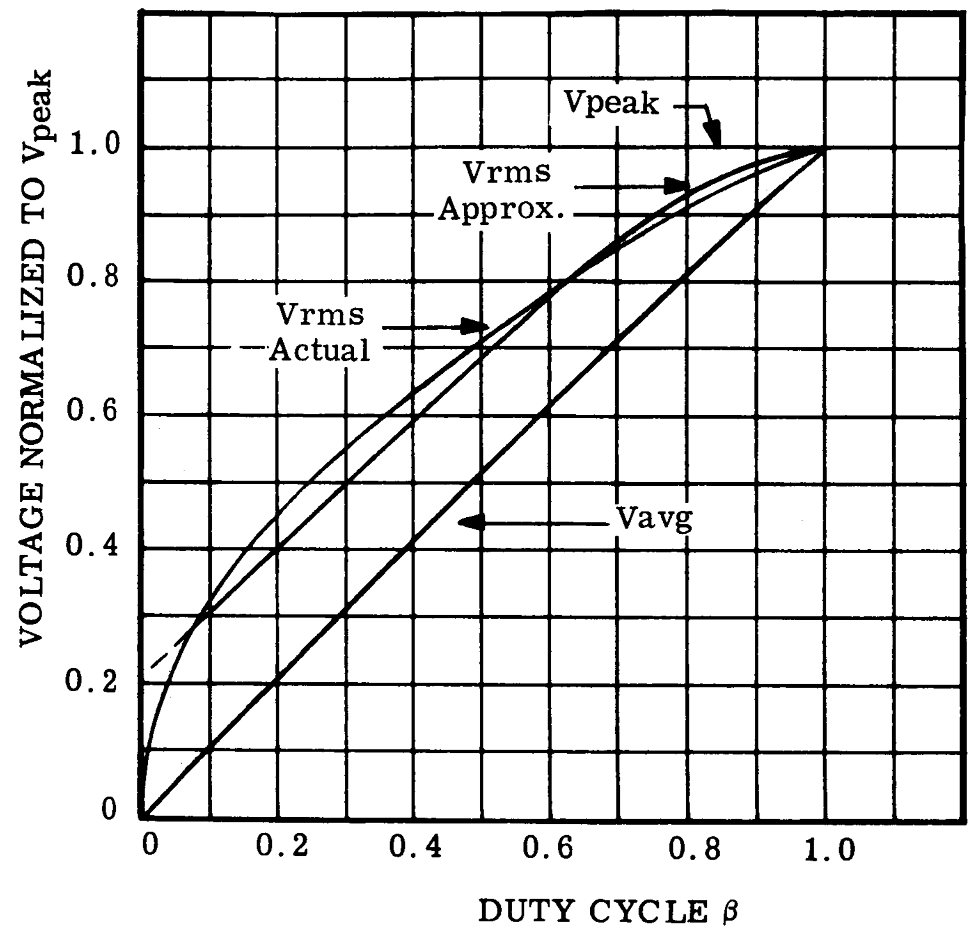


FIGURE 62. Actual and Approximate RMS Voltage Variations with Duty Cycle

A comparison of these two curves indicates that the rms voltage curve can be approximated by increasing the average voltage in the region of B = 0.5, but not in the region B = 0 or B = 1.0. The rms/dc converter performs this task.

During operation, input capacitor C_i charges rapidly to the peak value of the input squarewave. At the end of the squarewave, C_i discharges exponentially through R_i forming the waveshape shown in Figure 61. The area under the exponential portion of the curve adds to the area under the input squarewave in the region where B = 0.5, but not when B = 0 or when B = 1.0. The average of this waveshape is obtained by the output filter consisting of R_o and C_o.

Proper selection of R_i and C_i results in the approximate characteristic as shown in Figure 62. The error introduced by this circuit as a function of duty cycle B is shown graphically in Figure 63. In the case of a current-regulated output, normal operation occurs in the region where B > 0.5. Thus, the maximum error introduced by this circuit does not exceed 4 percent.

Although not yet completed, recent tests conducted on this circuit indicate that accuracies of 1.0 percent are possible over 80 percent of the pulse-width range.

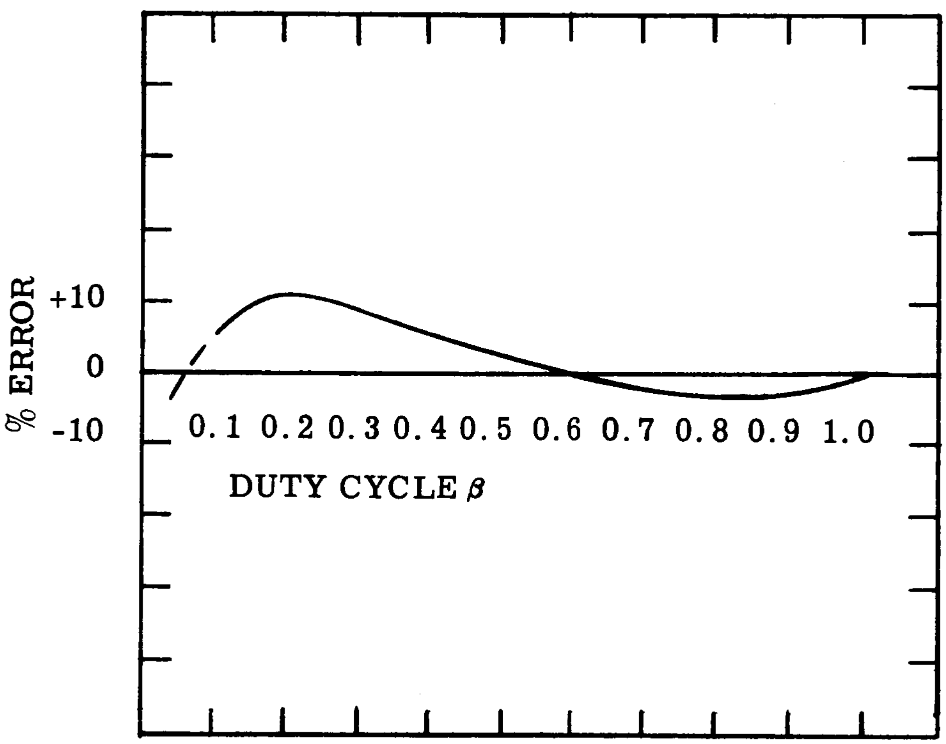


FIGURE 63. Percent Error of RMS/DC Converter Output Voltage as a Function of Duty Cycle

POSSIBLE IMPROVEMENTS

Efficiency and Weight

The efficiency of the power conditioner was measured to be approximately 70 percent under the conditions outlined in Table 1. The weight of the power conditioner components was calculated to be approximately 20 pounds. Since the power conditioner was designed for a total output power of 1372 watts, this corresponds to a specific weight of 14.58 pounds per kilowatt.

Table 1. Power Conditioner Efficiency Data

	Output		Power
	Volts	Amps	Watts
Feed	6.2	3	18.60
Cathode	4	30	120.00
Anode	35.5	3.5	125.25
Screen	2620	0.25	655.00
Accelerator	1900	0.05	95.00
Neutralizer Cathode	5.4	4.35	23.50
Neutralizer Vaporizer	3.1	2.65	8.20
Neutralizer Bias	55	0.06	3.30
Total Output	1048.85 watts		
Total Input	1485 watts	(33A, 45v)	
Efficiency	70.6 percent		

The major losses are attributable to the magnetic components and to the regulator components in the 10- and 30-volt supplies. The losses in the magnetic components could be reduced considerably by increasing both wire size and core size but would result in an increase in component weight.

An alternate approach would be to increase the operating frequency of the inverter. This would allow an increase in efficiency without additional weight. Since operation of the magnetic amplifiers becomes questionable at high frequencies, a two-inverter configuration should be considered. In this approach, the supplies presently controlled by magnetic amplifiers would be operated at a frequency compatible with the characteristics of the magnetic amplifiers and the engine, while the remaining supplies would be operated at much higher frequencies.

A third approach would be to incorporate transistor switching elements in lieu of the magnetic amplifiers, thereby eliminating the weight and losses associated with these devices. This approach, however, would require additional components to drive the transistors, thereby reducing the overall reliability of the power conditioner.

The losses associated with the 10- and 30-volt supplies are due in part to the regulator configuration, selected for its simplicity, and to the power requirements of the control circuits. The losses in the regulator can be reduced by utilizing pulse-width-modulated control such as offered by a magnetic amplifier. The losses in both the control circuit and the regulator can be reduced by utilizing integrated circuits wherever possible. One of the integrated circuit configurations presently used by Westinghouse AED in numerous areas can be used as a digital level detector, a monostable multivibrator, an analog amplifier, or a memory element, with demonstrated reliability and noise rejection capabilities.

Regulation

Several problems were encountered in attempting to meet the regulation requirements of the ac supplies. The major problem was caused by the location of the sensing transformers in relation to the load variables being measured. In all cases where this sensing was accomplished on the primary side of the output transformer, errors were introduced into the control signals. This error adversely affected the closed-loop operating characteristics of the controlled outputs and the accuracy of the telemetry information. The improvement in operation obtained by sensing the variables at the secondary of the output transformer was demonstrated in the neutralizer vaporizer supply. This method, however, would introduce additional transformer insulation problems when adapted to the ac outputs which are biased at high voltage levels.

The use of an integrated-circuit voltage level detector appears to be highly compatible with the required control characteristics of the regulated supplies. The use of avalanche diodes with a breakdown voltage of less than 6 volts is highly undesirable due to the less-than-ideal characteristics which would be exhibited. A differential amplifier available as an integrated circuit provides an ideal solution to this problem, and, contrary to the avalanche diode, requires no temperature compensation.

Signal Noise

Noise introduced into the control circuits of the power conditioner by the presence of high-current switching presented numerous problems. In all cases, these problems were caused by applying low-level signals to sensing circuits located some distance away. Small filter capacitors were necessary in some cases to reduce the noise to a tolerable level, while relocation of the circuits was necessary in others. Shielded cable may have provided sufficient noise rejection, but the elimination of all low-level signal leads would be the ultimate goal.

DUMMY LOAD AND TEST CONSOLE

The dummy load and test console provides a variable load for each of the power conditioner outputs along with associated metering devices. In addition, command functions, telemetry readouts and provisions for simulating short circuit and arc conditions are included.

Figures 64 and 65 show two photographic views of the completed unit. Features to provide personnel safety were considered to be of prime importance. A red warning light located on top of the unit is automatically energized when either positive or negative high voltages are present. In addition, clear Plexiglas panels allow easy viewing of the front-panel meters while preventing contact with components operating at high voltages. Interlocks operated by the front access door provide an off signal to disable the power conditioner, and cause a shorting bar to ground both high-voltage supplies.

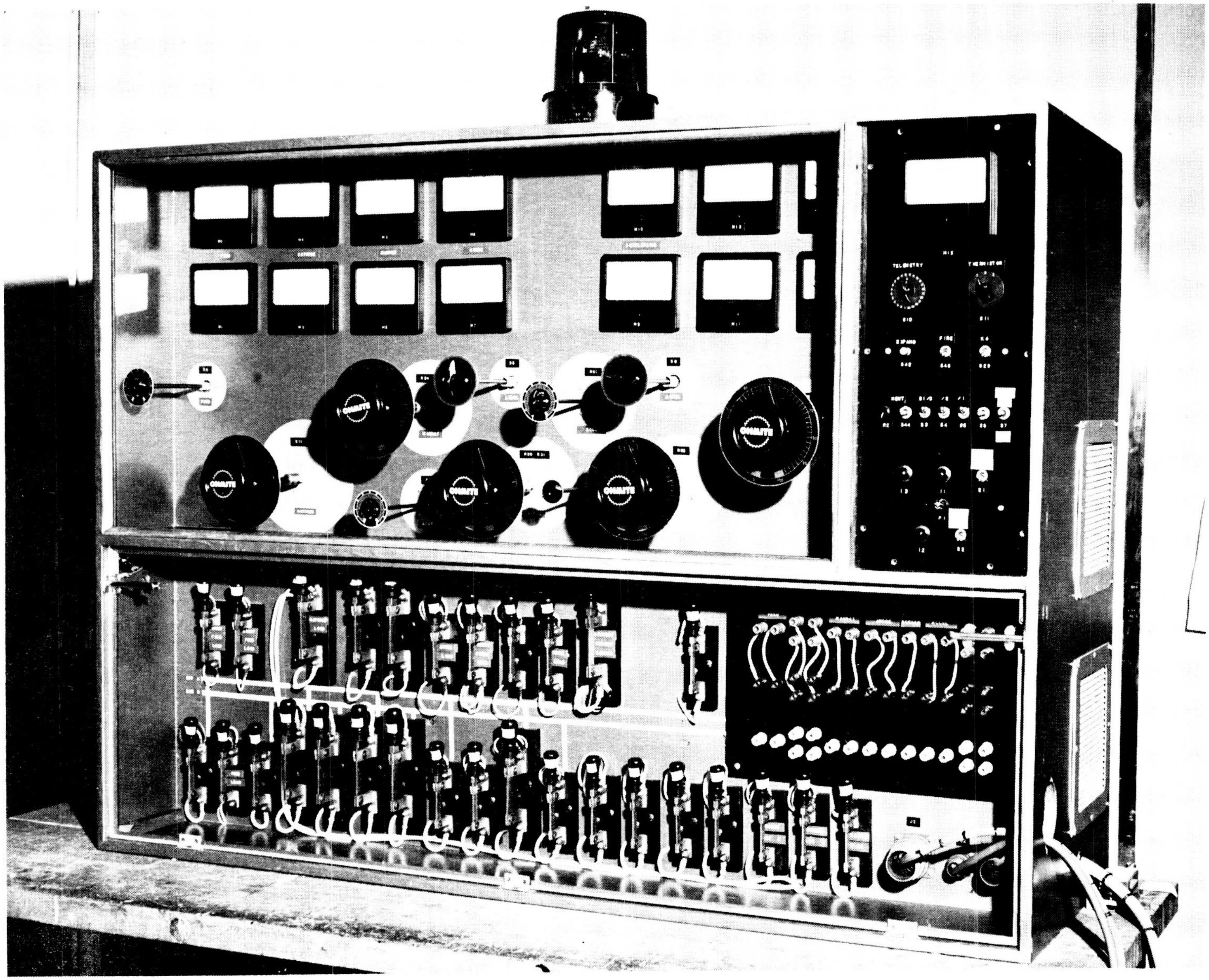


FIGURE 64. Front View - Dummy Load and Test Console

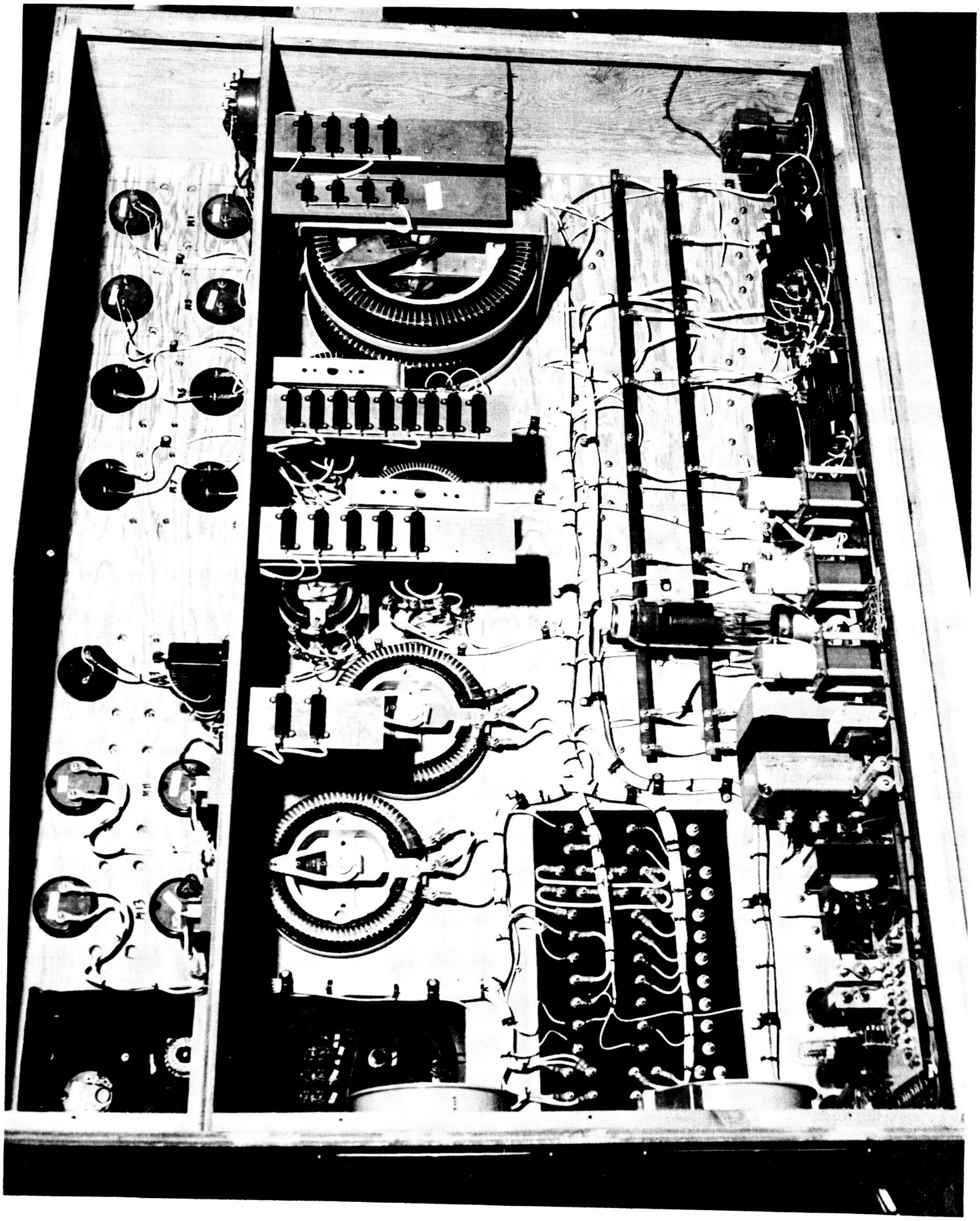


FIGURE 65. Internal Rear View - Dummy Load and Test Console

A schematic diagram of the unit is presented in Figure 66. The unit requires a 110-volt 60 Hz input for the various control and cooling functions. Time delay relay K2 prevents application of a high voltage to thyratron VI for 60 seconds upon startup. Lamp I2 senses closure of contact K2, thereby indicating that the unit is ready for operation.

The power conditioner power terminals are connected to the dummy load and test console by means of connecting leads emanating from the unit. By means of front panel knife switches, these terminals can then be connected to the appropriate variable load, or to one of two bus bars. The bus bars can be shorted to each other by means of relay K1 (with S40 closed), or may be used to simulate an arc condition by means of relay K8 (with K1 closed and S1 open). In this manner, any power conditioner output terminal may be shorted or an arc simulated to any other terminal, or to engine common.

Although NASA change order number 4 required a major redesign of the power conditioner neutralizer supplies, corresponding changes were not incorporated in the dummy load and test console. As a result, loading and monitoring of the neutralizer outputs must be accomplished externally. In addition, the command signal configuration, now obsolete, is replaced by the remote control panel delivered as a separate item with the power conditioner.

A detailed component parts list of the dummy load and test console is presented in the appendix.

CONCLUSIONS

The purpose of this contract was to develop a power conditioning unit capable of providing the necessary control functions associated with operation of mercury-ion electric thrustor engine. While efficiency, weight and reliability were considered the major design trade-offs, initial decisions led to the choice of magnetic amplifiers as control elements for purposes of simplicity and reliability. As a result, the weight of the unit was generally fixed.

Among the major problems encountered during the development phase were the areas of high voltage transformer insulation and the accurate measurement of load variables. The transformer problem was eliminated by careful redesign which limited the internal voltage gradients, and thorough potting of the completed unit. The accuracy of the load variable measurements was limited due to the location of the sensing circuits on the primary side of the output transformers, and was greatly improved in one case by relocating the sensing circuit in the secondary.

While the total number of components in the power conditioner appeared high when compared to the units developed under NASA contract NAS3-7420, this difference must be weighed in light of the difference in system requirements. Although the total component count could be reduced considerably by the use of integrated circuits, the total number of functions provided by these circuits would remain essentially unchanged.

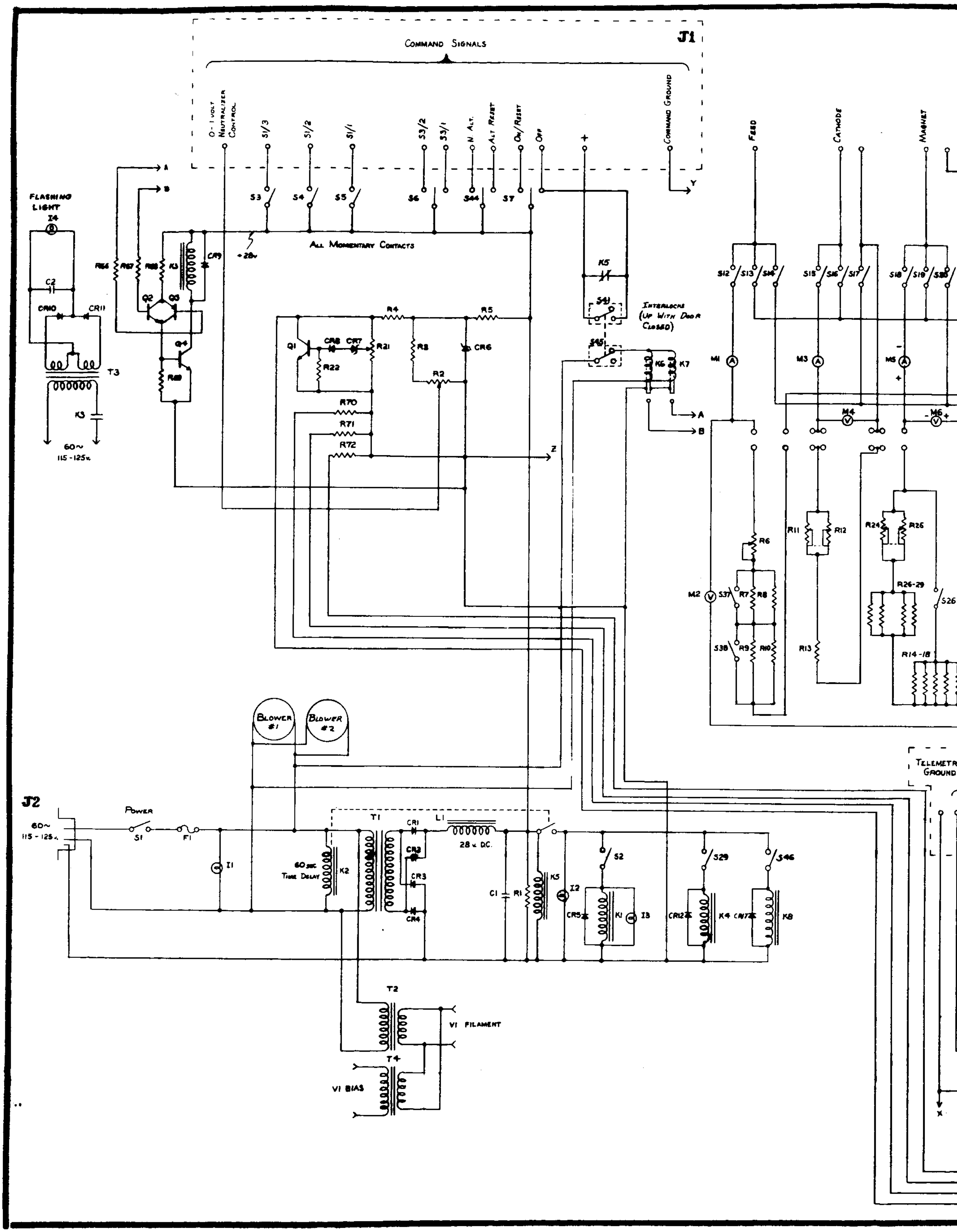


FIGURE 66. Schematic Diagram - Dummy Load and Test Console

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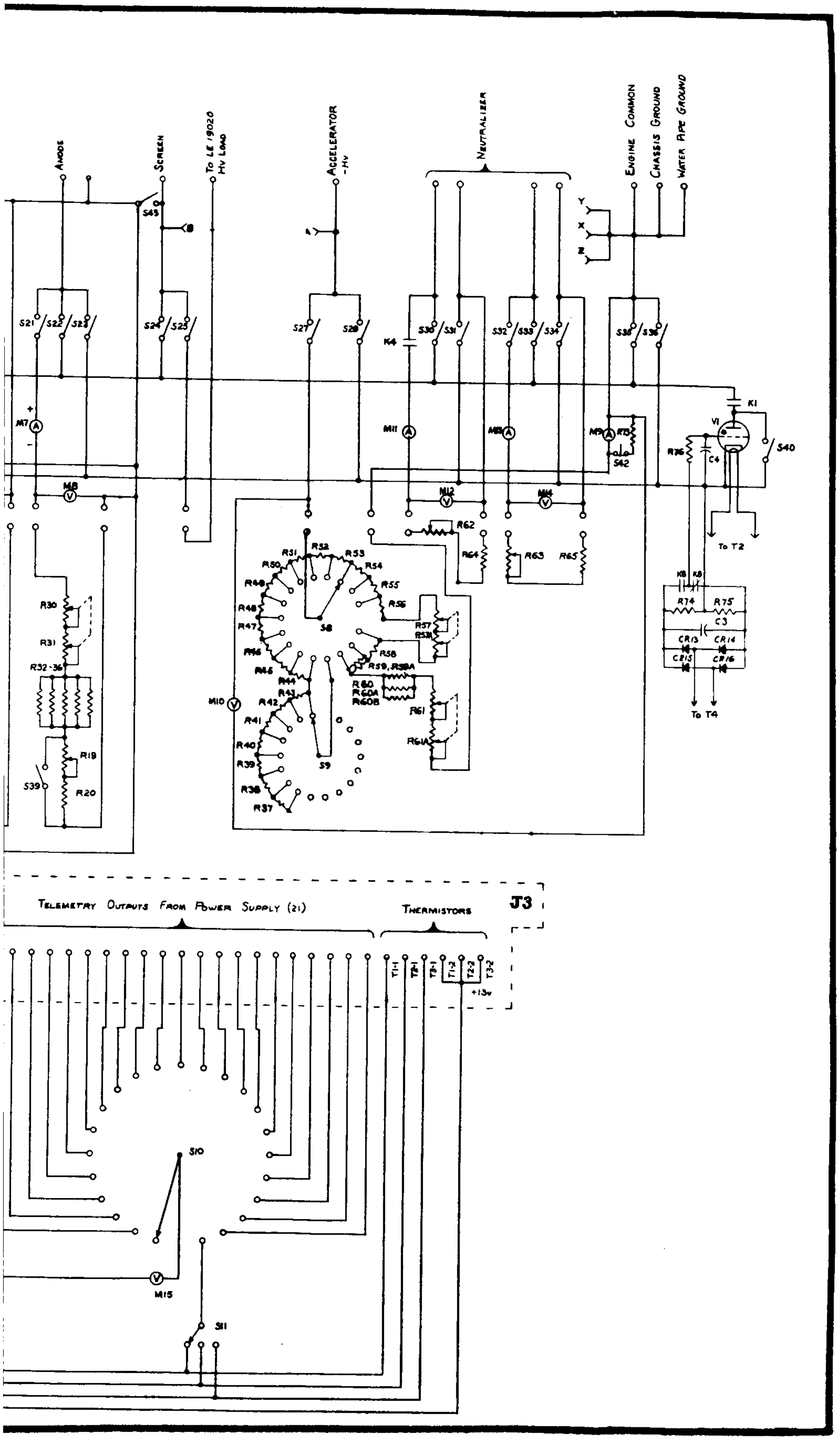

99-2 PRECEDING PAGE BLANK NOT FILMED.

APPENDIX A

COMPONENTS PARTS LIST - POWER CONDITIONER

Drawing No. EDSK 328236

For NAS 3-7938 B/B#1

Page Index

Page	Content	Component Numbers Used	Component Total
1-4	Revisions to Parts List		
5-6	Capacitors	C1 - C46 (C40 not used)	45
7-9	Diodes	CR1 - CR168 (CR125, CR126 not used)	166
10	Inductors	L1 - L3	3
11	Mag. Amps	AR1 - AR5	5
12	Relays	K1 - K9	9
12	Ckt. Breaker	CB1	1
13-19	Resistors	R1 - R164 (R110, R117, R121 - R125, R135, R139, R155 not used)	154
20-21	Transformers	T1 - T23	23
22	Transistors	Q1 - Q39	39
23-25	Accessories and Hardware		

REVISIONS

REMOVED: C2, C35, R115
ADDED: CR124 - CR129, R4, T20
CHANGED: CR39 from 30 volt 5 watt to 20 volt 10 watt; R40 from 11K ohm to 13K ohm; R129 from 16.2 ohm to 1 ohm; changed all terminals

H. R. H. 2.3.66

ADDED: 50M60180 to C18, C19; MIL-S-19500/124B to CR41; MIL-S-19500/272 to CR88 et. al.; MIL-R-19A to R13, R14; Note to CR55 et. al.

H. R. H. 2.4.66

ADDED: CR131 - CR136, Q25, R6, R118, R119, R120, R115
CHANGED: K5 from S4GH-2-22 to W 929A681-1; R44 from 250 ohm to 130 ohm; R130 from 2.2K ohm to 33 ohm; Q14 from 2N2658 to S2N2102; Q16, Q17 from 2N1016D to Solitron SES094; R132 from 2K ohm to 3K ohm; R109 from 25 ohm to 1.8K ohm; R49 from 20K ohm to 5K ohm

H. R. H. 2.7.66

CHANGED: R48, R49 from 10K ohm RPC type EBM to 5K ohm
REMOVED: R20

G. W. E. 2.11.66

CHANGED: R1 from 500 ohm to 510 ohm; R5 from 600 ohm to 620 ohm; R11 et. al. from 5K ohm to 5.1K ohm; R12 et. al. from 500 ohm to 510 ohm; R62 from 6.9K ohm to 6.8K ohm; R80 from 50K ohm to 51K ohm; R81 from 25K ohm to 24K ohm; R3, R127 from 50 ohm to 51 ohm; R28 et. al. bushing size from 3/8 to 1/4

H. R. H. 2.14.66

REMOVED: R117, C18, C19, CR122, Duplicate R120 1.8K ohm, Duplicate CR129 60 volts
CHANGED: R116 from 110 ohm to 9.1K ohm; CR121 from W 379H to S1N645
ADDED: Elapsed Time Meter information; Parts List Cover, page 1, page 20, and renumbered pages

P. K. 4.26.66

CHANGED: R44 from 35 watt to 15 watt 50M60185

R. M. W. 5.13.66

CHANGED: C22 from 33Mfd to 27Mfd; C28, C27 from 0.047Mfd to 0.056Mfd; CR124 from

REVISIONS

ADDED:	UZ5860 to UZ5760; C5, C6, C33 from W 929A495-1 to W 929A795-1 Number Req'd for all parts	R. M. W. 5.17.66
ADDED:	CR130 as UT4040	R. M. W. 5.24.66
ADDED:	Updated W Drawing No.'s	R. M. W. 8.26.66
REMOVED: CHANGED: ADDED:	The following CR's: 6, 7, 10, 12, 13, 14, 25, 31, 49, 74, 75, 89, 90, 91, 103, 110, 111, 115, 123, 127 The following R's: 2, 5, 7, 8, 9, 10, 27, 28, 30, 31, 32, 45, 47, 48, 49, 53, 55, 58, 62, 63, 64, 73, 75, 76, 80, 81, 82, 87, 90, 95, 100, 103, 104, 110, 112, 118, 119, 135, 149, 150 The following C's: 7, 27, 34 The following Q's: 5, 7, 21, 22 The following XFMR's: L2, AR5, T4, T20 The following K's: 5 CR112 from S1N746 to S1N752; AR4-AR5 from -1A type to -1N type; R51 from 1K ohm 1/2 watt to 110 ohm 1/2 watt; R54 from 3K ohm 1/2 watt to 20K ohm 1/2 watt; R57 from 300 ohm 1/2 watt to 3.9K ohm 1/2 watt; R132 from 3K ohm 1/2 watt to 510 ohm 2 watt CR137 - CR143, C36 - C40, R152 - R154, R156 - R164, Q26 - Q29 Number Req'd for all parts corrected	R. M. W. 9.12.66
ADDED:	UJT Ckt. Components: R53, R28, R27, CR75, C42, Q5	R. M. W. 9.13.66
ADDED: CHANGED:	K5, K6, K7 W 927A283-1; CR90, CR91, CR110, CR111 R132 from 510 ohm 2 watt to 500 ohm 5 watt	H. T. G. & R. M. W. 9.21.66
ADDED:	The following CR's: 115, 103, 123, 127, 144 The following R's: 2, 5, 7, 8, The following C's: 43, 44	R. M. W. 9.23.66
ADDED:	The following CR's: 31, 49, 74, 89, 25, 6, 7, 10, 12, 13, 14, 145 - 158	

REVISIONS

The following R's: 32, 49, 45, 103, 63, 55, 58, 62, 47, 104, 90, 112, 87, 118, 119, 80, 81, 82, 149, 150, 135, 64, 76, 73, 95, 100, 75
The following C's: 2, 7, 27, 34, 41, 45, 46
The following Q's: 7, 21, 22, 31, 32, 30
The following K's: 8, 9

CHANGED: R12 from 2 watt to 1/2 watt; R37 from 1.8K ohm to 3.9K ohm 1/2 watt; R68 from 1K ohm to 510 ohm 1/2 watt; R101 from 390 ohm to 1K ohm 1/2 watt

REMOVED: R34

R. M. W. 10.11.66

ADDED: L2, AR5, T4, T20 - T23; Parts List pages 2 and 3 and renumbered pages; Number Req'd for all parts corrected

R. M. W. 10.12.66

ADDED: Feed V2c Terminal

R. M. W. 10.26.66

ADDED: Grommet

R. M. W. 10.28.66

CHANGED: J1 from 15 pin to 26 pin connector (like one that was available)

R. M. W. 10.31.66

REMOVED: CR84, R52, R105

ADDED: CR122, CR84, CR159, CR160, R9, R10, R20, C18, C19, Q33

CHANGED: R159 from 20K ohm 1/2 watt to 2K ohm 1/2 watt to 1.5K ohm 1/2 watt; R127 from 51 ohm 2 watt to 51 ohm 1/2 watt; R91 from 100 ohm 2.1 watt to 150 ohm 1/2 watt; R22 from 1K ohm 1/2 watt to 820 ohm 1/2 watt; R131 from 3K ohm 1/2 watt to 5.1K ohm 1/2 watt; R128 from 1K ohm 1/2 watt to 5.1Kohm 1/2 watt to 5.1K ohm 1 watt; R47 from 130 ohm 1/2 watt to 430 ohm 1/2 watt; R135 from 130 ohm 1/2 watt to 300 ohm 1/2 watt; R66 from 2K ohm var. to 10K ohm var.; R41 from 3.9K ohm to 5.1K ohm 1/2 watt; C40 from 1.5 Mfd. to 5Mfd; C20 Sprague P/N 118P 30502S2 to P/N 118P 30592S2; CR 71 from 1N762 to UZ5710

R. M. W. 11.10.66

ADDED: Number Req'd for all parts corrected.

R. M. W. 11.11.66

REVISIONS

<u>REMOVED:</u> Columns for 1N3910, <u>W</u> 929A432-2 and UZ5730, <u>W</u> 929A770-5
<u>ADDED:</u> In above columns CR161-3; CR164 - CR166.

R. M. W. 11.14.66

<u>REMOVED:</u> C18, C40, R139, R106, R135, CR84, CR14, CR25, CR125, CR126, T21, Duplicate C2 M Mfd. 35 volt
<u>ADDED:</u> C18, R52, R30, R31, R34, R48, R137, R138, R105, R106, Q34, Q35, Q37, Q38, Q36, L3 and T21, CR84, CR14, CR25, CR167, CR168
<u>CHANGED:</u> R99 from 1K ohm 1/2 watt to 3K ohm 1/2 watt;
R101 from 1K ohm 1/2 watt to 620 ohm 1/2 watt;
R88 from 1K ohm 1/2 watt to 300 ohm 1/2 watt;
R91 from 150 ohm 1/2 watt to 330 ohm 1/2 watt;
R45 from 1K ohm 1/2 watt to 1.8K ohm 1/2 watt;
R85 from 1K ohm 1/2 watt to 510 ohm 1/2 watt;
R55 from 1K ohm 1/2 watt to 510 ohm 1/2 watt;
R83 from 1K ohm 1/2 watt to 3K ohm 1/2 watt;
R107 from 430 ohm 1/2 watt to 330 ohm 1 watt;
R93 from 1K ohm 1/2 watt to 3K ohm 1/2 watt;
R71 from 1K ohm 1/2 watt to 2.4K ohm 1/2 watt; C16 from 2.2Mfd. 20v to 10Mfd. 35v; CR116 from UZ5710 to UZ5730; CR7 from S1N645 to S1N752A; CR99 from S1N645 to S1N752A

R. M. W. 11.22.66

<u>ADDED:</u> S1 (Thermostat); S2, S3, S4 (Switches); F1 (Fan);
Pages 3, 9, 18 and renumbered pages accordingly;
Number req'd for all parts corrected

R. M. W. 11.23.66

<u>ADDED:</u> Q39

R. M. W. 1.3.67

TITLE
PARTS LIST REVISIONS
NAS 3-7938 POWER CONDITIONER

DWG. NO. EDSK 328236

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
C1, 21	2	Tantalum, Solid 10MFD, 20V	CS13B	MIL-C-26655/2 (W) 929A478-1 3/16 x 1/2
C3,4,7,10,13,14, 17,42,43,44	10	Tantalum, Solid 2.2MFD, 20V	CS13B	MIL-C-26655/2 (W) 929A478-3 9/64 x 5/16
C8,9,11,36,34	5	Tantalum, Solid 5.6MFD, 35V	CS13B	MIL-C-26655 (W) 906D715-40 .186 x .454L
C20	1	Paper Mylar, Met. 3MFD, 200V, 125°C	None	MIL-C-18312 929A477-4 Sprague P/N 118P30592S2 .670 dia x 1-7/8
C12,15,29	3	Tantalum, Solid 1MFD, 35V	CS13B	MIL-C-26655 (W) 906D715-43 .135 x .286L
C22	1	Tantalum, Solid 27MFD, 20V	CS13B	MIL-C-26655 929A478-11 .351 x .786L
C23,24	2	Paper Mylar Foil .01MFD, 7500V, 125°C	None	Dearborn P/N GTL37R103 930A432-1
C35,37,38	3	Tantalum, Solid 100MFD,20V	CS13B	MIL-C26655/2 (W) 929A478-4
C25,26,32,41, 2, 18	6	Tantalum, Solid 0.1MFD, 35V	CS13B	MIL-C-26655/2 (W) 906D715-22 .135 x .286L
C33, 5,6	3	Tantalum, Etched Foil 25MFD, 100V	CL21C	MIL-C-3965/17 (W) 929A795-1 25/64 x 2-1/8

CAPACITORS
AED 1620 ENG

NAS3-7938
ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
C28	1	Tantalum, Solid 0.056MFD, 35V	CS13B	MIL-C-26655/2 (W) 906D715-17 .135 x .286L
C30,31,27	3	Tantalum,Solid .33MFD,35V	CS13B	MIL-C-26655/2 929A478-12 .135x .286L
C39	1	5MFD, 150V	None	
C45	1	1MFD, 400V	None	
C46	1	5MFD, 60V	None	
C16	1	10MFD, 35V	None	

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
CR1,115,15,22,27 35,45,72,83,87, 112,98,104,105,	23	Zener 5.6V 0.4W	MSFC-Spec 338/8	(W) 929A775-1 SIN752
113,114,129,127, 89,6,10,7,99				
CR2-5,8,9,11-14, 17-19,23-26,28- 30,32,33,40,46-	66	Diode 225V 0.4A	None	(W) 929A774-1 SIN645
48,61,62,73,75, 80-82,85,86,90, 91,101-103,108-				
111,117,118,121- 123,131-133,136, 149-159,167,168				
CR161-163,166	4	Zener 100V 10W	None	938D390-15
CR15,71,137,138	4	Zener 10V 5W	None	929A770-4 UZ 5710 Unitrode
CR20,21,144	3	Zener 6.8V 5W	None	929A770-3 UZ 5706 Unitrode
CR34,42,79,31	4	Zener 6.0V .25W	MSFS-Spec 338/9	930A443-1 SIN762
CR36,37,50-54, 64,69,70,63,76, 77,49,74,134,	18	Rectifier 400V 4A	None	930A445-1 UT4040 Unitrode
135,130				

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
CR38	1	Zener 40V 5W	None	929A770-6 UZ 5740 Unitrode
CR164,165	2	Zener 175V 50W	None	IN3348RB
CR41	1	10V 10W	None	MIL-S-19500/1248 938D390-53 IN2974B/USN
CR43,44	2	Rectifier 400 12A	MSFC-Spec 338/13	929A776-1 SIN1204A
CR55,56,78,95, 96,128,142,143	8	Rectifier 600V 1A	None	Will use UTR146 if available; otherwise will use UTR61 - 927A496-8
CR57-60,65-68	2	High Voltage Bridge 500MA 8000V	None	Special Package from Unitrode 929A649-4
CR39	1	Zener 20V 10W	None	Motorola IN2984B 938D390-91
CR88,92,97,100	4	Zener 4.7V 10W	None	MIL-S-19500/272 IN3995A 938D390-81
CR93,94,106,107 119,120	6	400V 12A High Sp.	None	929A778-4 (W) 379H Flat Pack
		Zener 3.3V 0.4W	MSFC-Spec 338/8	929A775-3 SIN746

Diodes
AED 1620 ENG

NAS3-7938

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
CR124	1	Zener 60V 5W	None	929A770-7 UZ 5760 Unitrode
CR139,140,141	3	Zener 170V $\pm$ 10%	None	UZ 117 929A680-6
CR84	1	Rectifier 100V 35A High Speed	None	IN3910
CR145-148	4	Diode	None	IN648 906D976-4
CR160	1	Syl. IN2071	None	
CR116	1	Zener 30V 5W	None	UZ 5730

Inductors
AED 1620 ENG

NAS3-7938
ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
L1	1	Filter, Input 100 mHy	None	A-81 Core (W) 908D138-5 (W) D-Spec 773750
L2	1	Filter Neut. Bias 54 mHy	None	Core 939D449-4
L3	1	Chore Neut. Cath. I7 Sensing 860 mHy	None	Torotel POG-59 860MH 15/63

NAS3-7938

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	N's used to be A's (are A's in BB #1) REMARKS
AR1	2	Transductor, Input Current,	None	52374-ID Magnetics Inc. Core. 939D924-25 (W) D-Spec 709795
AR2	2	Feed	None	52018-IN 939D924-18 (W) D-Spec 709796
AR3	2	Neutralizer Cath.	None	52030-IN 939D924-19 (W) D-Spec 709797
AR4	2	Cathode	None	52139-IN 939D924-21 (W) D-Spec 709798 -IN used in BB#1
AR5	2	Neutralizer Vap.	None	52030-IN 939D924-19 -IN used in BB#1

NAS3-7938
ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
K1,2,3,4,8,9	6	2PDT, 28V, 900 Ohm coils 175MW Sensitivity 2ADC Contacts	None	.4 x .4 x .41 (W) 929A681-1
K5,6,7	3	2PDT, 28V, 600 Ohm coils 10ADC Contacts	None	927A283-1
CB1	1	Magnetic, Single Pole 50 A DC	None	4-9/16 x 2-17/32 x 2-1/2 941D896-2 Woodelectric Model 130

Resistors, Fixed
AED 1620 ENG

NAS3-7938
ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
R1,90,12,68,52, 85,55	7	510, 5%, 1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-41
R84,63,21,89,23, 33,94,38,42,43, 86,32,67,98,106	17	1K, 5% 1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-55
72,112				
R34	1	100 Ohm 5%, 1/2W, 70°C CC	RC20GF	
		390,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-7
R2,101	2	620, 5%, 1/2W, 70°C CC	RC20GF	928A739-11
R71	1	2.4K,5%, 1/2W, 70°C CC	RC20GF	909C790-32
		400,5%, 2.1W, 125°C Wirewound	SRW69V	50M60188 929A744-4
R45,109,87	3	1.8K,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-93
R44	1	130,1%,15W, 70°C W.W.	None	MIL-R-18546C(RE70) 929A745-5

NAS3-7938
ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
Ri5,6	2	16M,5%,2W, 75°C High Voltage, 15KV	None	RPC Type EFQ-16M± 5% 930A119-1
R16,29,54,158, 161,163,5	7	20K,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-37
R17,	1	100,5%, 2.1W, 125°C W.W.	SRW69V	50M60188 929A744-5
R18	1	50,5%,4.5W, 125°C W.W.	SRW67V	50M60188 929A744-6
R24	1	470,5%,1W, 70°C CC	RC32GF	MIL-R-11/6 P11D3300-47
R7,25	2	110,5%,2W, 70°C CC	RC42GF	MIL-R-11/7 908D276-22
R26,35,56,60,74 113,4,28,151, 156,157,82	12	10K,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-10
R11,136,142,53, 49,104,118,131, 41	9	5.1K,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-58
R134,140,141, 119	4	510,5%,2W, 70°C CC	RC42GF	MIL-R-11/7 908D276-14
R40	1	13K,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-25

Resistors, Fixed
AED 1620 ENG

ELECTRICAL PARTS LIST

NAS3-7938

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
R57,37	2	3.9K,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-16
R19,70,78	3	100K,1% 25°C Thermistor	None	Gulton No. L794-51CA1 962C931-1
R46,27,75,146 148	5	2K,5%,1/2W,70°C CC	RC20GF	MIL-R-11/3 909C790-20
		5K5%,1W, 75°C 15KV Peak	None	Pyrofilm Resistor Co. 929A669-2 Type PT2000 .218 x 2.03L
		7.5K,5%,1/2W,70°C CC	RC20GF	MIL-R-11/3 909C790-22
R80,20,61,99,83, 93,143	7	3K5%,1/2W,70°C CC	RC20GF	MIL-R-11/3 909C790-53
R10,59,120,88	4	300,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-5
		6.8K,5%,1/2W,70°C CC	RC20GF	MIL-R-11/3 909C790-11
R159	1	1.5K,5%,1/2W,70°C CC	RC20GF	MIL-R-11/3 909C790-45
		360,1%,12W, 125°C W.W.	SRE75G	50M60185 929A745-4

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
R8	1	20,1%,2W, 125°C W.W.	None	MIL-R-26C P19C7558-66
R127	1	51K, 5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-38
		24K,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-23
R3	1	51,5%,2W, 70°C CC	RC42GF	MIL-R-11/7 908D276-21
R96,62,100	3	130,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-2
R97,47	2	430,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 928A739-12
R102,51,153,150	4	110,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 928A739-13
R9	1	680,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 928A739-61
R126	1	150,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 928A739-62
R108	1	180,5%,1/2W,70°C CC	RC20GF	MIL-R-11/3 928A739-14

Resistors, Fixed
AED 1620 ENG

NAS3-7938
ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
R130	1	33,5%,2W,70°C CC	RC42GF	MIL-R-11/7 908D276-1
R116	1	9.1K,5%,1/2W, 70°C CC	RC20GF	MIL-R-11/3 909C790-49
R115	1	9.1K, 5%,2W, 70°C CC	RC42GF	MIL-R-11/7 908D276-24
R133	1	75,5%,2W, 70°C CC	RC42GF	MIL-R-11/7 908D276-25
R128,137,138	3	5.1K,5%,1W, 70°C CC	RC32GF	
R129	1	1.0,5%.7.6W, 125°C W.W.	SRW68V	50M60188 929A744-9
		100K,1%, 25°C Thermistor	None	Victory Engrg. Corp. P/N 51A107 962C930-1
		33,5%, 1/2W, 70°C CC	RC20GF	MIL-R-11/3 928A739-15
R144,152,81,22	4	820,5%,1/2W, 70°C CC	RC20GF	909C790-47
R145	1	200,5%, 4.5W, 125°C W.W.	SRW67V	50M60188 929A744-7

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
R147	1	160,5%,4.5W, 125°C W.W	SRW67V	50M60188 929A744-8
R160,162	2	150K,5%,1/2W 70°C CC	RC20GF	
R164	1	1K,5%, 10W	None	
R132	1	500 Ohm 5W	None	
R149	1	100K Ohm 1/2W	RC20GF	
R30	1	680 Ohm 1W	RC32GF	
R31	1	390 Ohm 5%, 1W, 70°C CC	RC32GF	
R91	1	330 Ohm 5%, 1/2W, 70°C CC	RC20GF	
R107	1	330 Ohm 5%,1W, 70°C CC	RC32GF	
R48	1	82K Ohm 5%,1W, 70°C CC	RC32GF	
R105	1	3K Ohm 5%, 1W, 70°C CC	RC32GF	

Resistor, Variable
AED 1620 ENG

NAS3-7938
ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
R13,14	2	75,10%,4W,70°C W.W	None	MIL-R-19A 18C4722-11 MIL Style RA30LASB
R58,36,69,79	4	500,10%, 1/2W, 70°C	None	MIL-R-94/3 929A748-1 1/4 Bushing RV6LAYSA
R64,76,73,95, 114,66	6	10K,10%,3/4W, 85°C	None	929A474-4 MIL No. RT22C2L
R50	1	100K, 10%,3/4W, 85°C	None	929A474-7 MIL No. RJ22BL 1/2 x 1/2 x .187
R65,92,154	3	1K,10%,3/4W, 85°C	None	929A474-5 MIL No. RT22C2L 1/2 x 1/2 x .187
R77,39,103	3	2K,10%,3/4W, 85°C	None	929A474-6 MIL No. RT22C2L 1/2 x 1/2 x .187
R111	1	50K, 10%,3/4W, 85°C	None	929A474-8 MIL No. RJ22BL 1/2 x 1/2 x .187

Transformers
AED 1620 ENG

NAS3-7938
ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
T1	1	Power,Main Inverter	None	H-406 908D090-60 (W) D-Spec 709779
T2	1	Controlled Current Geedback	None	52481-1D 939D924-26 (W) D-Spec 709780
T3	1	Current, Screen	None	52011-1D 939D924-17 (W) D-Spec 709781
T5	1	Current Feed	None	52011-1D 939D924-17 (W) D-Spec 709783
T6	1	Power Feed	None	H-250 908D090-56 (W) D-Spec 709784
T7,4,23	3	Voltage, Feed, Neut. Vap., Neut. Bias	None	52007-1D 939D924-16 (W) D-Spec 709785
T8	1	Current Neut.	None	52011-1D 939D924-17 (W) D-Spec 709786
T9	1	Voltage, Neut.	None	52007-1D 939D924-16 (W) D-Spec 709785
T10	1	Power	None	H-250 908D090-56 (W) D-Spec
T11	1	Current Cathode	None	52011-1D 939D924-17 (W) D-Spec 709788

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
T12	1	Voltage, Cathode	None	52007-1D 939D924-16 (W) D-Spec 709785
T13	1	Power, Cathode	None	H-129 908D090-17 (W) D-Spec 709789
T14	1	Current, Anode	None	52033-1D 939D924-20 (W) D-Spec 709790
T15	1	Voltage, Anode	None	52007-1D 939D924-16 (W) D-Spec 709785
T16	1	Power, Anode	None	H-372 908D090-45 (W) D-Spec 709791
T17	1	Current, Main Inv.	None	52011-1D 939D924-17 (W) D-Spec 709792
T18	1	Power	None	H-252 908D090-38 (W) D-Spec 709793
T19	1	Jensen Timer	None	52167-1A 939D924-22 (W) D-Spec 709794
T20	1		None	H-250 908D090-56
T21	1		None	52011-1D 939D924-17
T22	1		None	52481-1D 939D924-26

Transistors
AED 1620 ENG

NAS3-7938
ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
Q1,2	2	Silicon Power 200V 65A	None	40A Peak, 120V Max. Oper. 929A428-1 MHT 8907 or STC 2118
Q3,6,23,24,30,9, 10,39,14,25-29, 21,7,22,31-36	23	Silicon NPN 120v 1A	MSFC-Spec 338/115	929A777-1 S2N2102
Q4,5	2	Silicon Unijunction	MSFC-Spec 338/103	930A341-1 S2N491B
Q8,11,13,19	4	Silicon NPN 40V,.2A	MSCF-Spec 338/106	930A342-1 S2N708
Q12,20	2	Silicon PNP 50V, .5A	NSFC-Spec 338/108	930A444-1 S2N722
Q15,18	2	Silicon NPN 100V, 5A	None	929A772-1 2N2658
Q16,17	2	Silicon NPN 200V 30A	None	18 A Peak, 120V. Max. Oper 929A429-1 Solitron SES094
Q37,38	2	Silicon NPN 200V, 10A	None	MHT 7612

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
Power Cond. Terminals	18	Five-way Terminal Posts, 2000 V DC, 30A	None	H.H. Smith Type 257 Red Black 917B075-6 917B075-5
Command J1	1 5	Connector 1-1/4" 1 Plug 15 Pins 5Recep.	MS3120E-16-26S MS3126F-16-26P	14 of #20, 928A038-15 1 of #16, 930A121-1
Input Power J2	5 1	Connector 1-3/8" 5 Plug 2 Pins 1Recep.	SK-S2-21C-5/8 SK-S2-32S	930A122-1 930A123-1
Telemetry J3	1 5	Connector 1-1/4" 1 Recep. 32 Pins 5 Plug	MS3120E-18-32S MS3126F-18-32P	928A038-16 32 of #20 930A121-2

Hardware, Breadboard Model
AED 1620 ENG

NAS3-7938

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
Cabinet	1	Prestige Type C-1551	None	
Circuit Boards	9	Vector Board Type 838 Receptacle Type R644	None	
Chassis	1	Bud Type AC-419 <Bottom Plate Type BPA-1598)	None	
Heatsinks	5	Wakefield Type 400; 5" Lengths	None	
Panel	1	Bud Type PA-1105	None	
Micarta Insul.	1			2 x 17 x 1/8 PDS 259-2
Etching Stock, Micarta		Nameplate Stock		2 x 17 x 1/16 PDS 44301EL
Elapsed Time Meter		Haydon Model K19703-G4 1 Hour -- 9,999 Hour		MIL-M 77936 928A046-2
#28 H.V. Wire #22 H.V. Wire	200' 200'	Mono-Tet Cable		
#18 H.V. Wire #14 H.V. Wire #10 H.V. Wire	100' 100' 100'			

Misc.
AED 1620 ENG

NAS3-7938

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
Grommet	11	Fit 0.625 Dia Hole for 1/8 Tk. material		956C905-8
Thermostat S1	1	G.V. Controls Type VE-2 (Close on Rise)		Temp. Setting 100°C
Fan F1	1	Rotron Skelton Fan Mark IV		Allied Stock 60D8599
S2	1	IPDT Switch Mom-on-Mon		
S3	1	IPDT Switch Mon-on-Mon		
S4	1	2P 8 Position Rotary Switch		

APPENDIX B

COMPONENT PARTS LIST -

DUMMY LOAD AND TEST CONSOLE

DRAWING NO. EDSK 328253

CONTRACT NAS 3-7938

REVISIONS

COMPONENT PARTS LIST DUMMY LOAD AND TEST CONSOLE CONTRACT NAS 3-7938	DWG. NO. EDSK 328253 PAGE 1 of 21

BLOWERS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
B1, B2	2	Blowers		Roton Feather Fan w/Filter

CAPACITORS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
C4	1	0.01 mfd. 200v		
C1	1	10 mfd. 50v Tantalum		906D715
C2	1	20 mfd. 30v Tantalum		906D715
C3	1	26 mfd. 150v-200v		

DIODES

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
CR1, CR2, CR3, CR4	4	100v 6a		Westinghouse 366B
CR5	1	1N645		906D976-1
CR6	1	16v Zener 1w		1N4745A
CR7	1	13v Zener 400mw		1N964B
CR8, CR9	2	1N645		906D976-1
CR10, CR11	2	50v 5a		Westinghouse 366A
CR12-17	6	1N645		906D976-1

FUSES

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
F1	1	3AG 5a 250v		

LAMPS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
I1	1	Lens Type B0110 (Red)		Sylvania Type 120 PSB/B0099
I2	1	Lens Type B0112 (Green)		Sylvania Type 28PSB/B0099
I3	1	Lens Type B0110 (Red)		Sylvania Type 28 PSB/B0099
I4	1	12v 3a		Rotating Flasher Safety Light

RECEPTACLES

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
J1	1	Command Output		(15 pin) MS-3102A-28-175 & MS-3106A-28-17P
J2	1	Power Input		(3 pin) MS-3102A-165-55 & MS-3106A-165-5P
J3	1	Telemetry Input		(30 pin) MS-3102A-32-85 & MS-3106A-32-8P

RELAYS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
K1	1	15Kv 75a		Jennings Type RF10A
K2	1	60sec TDR		Amperite Type 115N060
K3	1			Hi-G Type C1B-126
K4,8	2	15Kv 75a		Jennings Type RF10A
K5	1			Hi-G Type C1B-126
K6,7	2	115 volt Solenoid Cont. Duty		Allied 77Z550

INDUCTORS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
L1	1	0.32 hy 600ma 10 ohm		Knight Allied 64Z702

METERS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
M1	1	0-20a AC 2%		
M2	1	0-10v AC 2%		
M3	1	0-60a AC 2%		
M4	1	0-5v AC 2%		
M5	1	0-50a DC 2%		
M6	1	0-10v DC 2%		
M7	1	0-10a DC 2%		Weston Inc.
M8	1	0-150v DC 2%		
M9	1	0-10ma DC & Shunt 2%		
M10	1	0-3000v DC 2%		
M11	1	0-25a AC 2%		

METERS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
M12	1	0-5v AC 2%		
M13	1	0-25a AC 2%		
M14	1	0-5v AC 2%		
M15	1	0-10v DC 1%		

TRANSISTORS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
Q1	1	NPN 2N2102		914F298-2
Q2	1	NPN 2N708		
Q3	1	PNP 2N722		
Q4	1	NPN 2N2102		914F298-2

RESISTORS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
R1	1	2K ohms 1w cc		P11D3300-6
R2	1	100 ohms 1w Pot		906D949-20
R3	1	1400 ohms 1/2w cc		909C790-45
R4	1	100 ohms 1/2w cc		909C790-1
R5	1	500 ohms 1/2w cc		909C790-41
R6	1	3 ohms 150w Pot		Knob 5109-A Ohmite Mod. L-0527 Dial 5000
R7, R8	2	1.5 ohms 50w ww		19C8414-9
R9, R10	2	0.5 ohms 50w ww		19C8414
R11, R12	2	1 ohms 1000w Pot		Knob 5104-A Ohmite Mod. U-1450-T2 Dial 5001
R13	1	0.0133 ohms 50w ww		19C8414
R14, R15, R16, R17, R18	5	0.6 ohms 50w ww		19C8414

RESISTORS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
R19	1	250K ohms 2w Pot		906D947
R20	1	2K ohms 1w cc		P11D3300-6
R21	1	1K ohms 1w Pot		906D949-17
R22	1	10K ohms 1/2w cc		909C790-10
R23	1	None		None
R24, R25	2	1 ohm 225w Pot		Ohmite Mod. P-1250-T2 Knob 5104-A Dial 5001
R26, R27, R28, R29	4	0.5 ohms 50w ww		19C8414
R30, R31	2	5 ohms 300w Pot		Ohmite Mod. N-0654-T2 Knob 5104-A Dial 5001
R32, R33, R34, R35, R36	5	10 ohms 50w ww		19C8414-10
R37	1	1 Meg ohm 1/2w cc		909C790-8
R38	1	500K ohms 1/2w cc		909C790

RESISTORS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
R39	1	300K ohms 1/2w cc		909C790
R40, R41	2	200K ohms 1/2w cc		909C790-54
R42, R43	2	150K ohms 1/2w cc		909C790-84
R44, R45, R45, R47, R48	5	100K ohms 1w cc		P11D3300-4
R49, R50, R51	3	100K ohms 2w cc		
R52, R53	2	100K ohms 5w		RPC Type BBV
R54, R55	2	100K ohms 10w		RPC Type BFW
R56	1	130K ohms 35w		Type DZW
R57, A	1	50K ohms Pot		Ohmite Mod. J-4215-T2
R58	1	15K ohms 50w		Ohmite Type 0416
R59, 59A	2	30K 100w		Ohmite Type 0620

RESISTORS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
R60,60A,60B	3	75K 100w		Ohmite Type 0624
R61,A	2	15K ohms 150w Pot		Ohmite Mod. L-4240
R62, R63	2	1 ohm 500w Pot		Ohmite Mod. R-0849 Knob 5104-A Dial 5001
R64, R65	2	0.1 ohms 50w ww		19C8414
R66, R67	2	10 Meg. ohms 4w		RPC Type EFQ
R68	1	30K ohms 1/2w cc		909C790-24
R69	1	10K ohms 1/2w cc		909C790-10
R70, R71, R72	3	1K ohm 1/2w 1%		IRC Type RN170C
R73	1	Meter Shunt		
R74	1	36K ohms 1/2w cc		909C790-30
R75	1	15K ohms 1/2w cc		909C790-48

RESISTORS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
R76	1	100K ohms 1/2w cc		909C790-21

SWITCHES

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
S1, S2, S46	3	SPST		Cutler-Hammer Type 7500K14
S3,S4,S5	3	SPST N.O. Mom.		Cutler-Hammer Type 7506K4
S6, S44	2	SPDT Mom.-Off-Mom.		Cutler-Hammer Type 8812K14
S7	1	SPDT Mom.-Off-On		Cutler-Hammer Type 8834K5
S8	1	17 Position		917B109-2 3000v Insul. Between Terminal
S9	1	8 Position		917B109-13 3000v Insul. Between Terminal
S10	1	23 Position		Centrallab PA-4001 Allied 36Z244
S11	1	3 Position		DP Allied P/N 35Z235
S12,S13,S14	3	SPST Knife Sw.		Barkelew Type 1002
S15,S16,S17,S18, S19, S20	6	SPST Knife Sw.		Barkelew Type 1003
S21,S22,S23	3	SPST Knife Sw		Barkelew Type 1002

SWITCHES

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
S24, S43	2	SPST Knife Sw.		Barkelew Type 1003
S25	1	SPST Knife Sw.		Barkelew Type 1002
S26	1	SPST Knife Sw.		Barkelew Type 1003
S27, S28	2	SPST Knife Sw.		Barkelew Type 1002
S29	1	SPST		Cutler Hammer Type 7500K14
S38,S39,S40 S34,S35,S36,S37, S30,S31,S32,S33,	11	SPST Knife Sw.		Barkelew Type 1002
S41, S45	2	Form C		Controls Co. of Am. Type C2
S42	1	SPST Mom.		Alcoswitch Type 105F-Red

TRANSFORMERS

AED 1620 ENG

ELECTRICAL PARTS LIST

ITEM	QTY.	DESCRIPTION	APPROVED LIST	REMARKS
T1	1	26.8v 1a		Triad Type F-40x
T2	1	5v 7.50a 15000v		Thordarson Meissner P/N 25F39
T3	1	117v 50-60cps Multi-Tap		Allied Radio P/N 62Z332
T4	1	V1-Bias xfmr.		Chicago Stancor P/N P6467

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